Energy Research and Development Division
FINAL PROJECT REPORT

PREDICTABLE AND LOW COST CONCENTRATING PHOTOVOLTAICS FOR CALIFORNIA COMMUNITIES

Appendix A-C

Prepared for: California Energy Commission
Prepared by: Cool Earth Solar

JULY 2016
CEC-500-2016-052-AP

APPENDIX A

Appendix A: Critical Project Review

Critical Project Review

PON-12-502-25
PIR-12-016
Community Scale Renewable Energy Development, Deployment and Integration

Cool Earth Solar

Innovative solar power

Jim Tietz, Paul Dentinger, Rob Lamkin

August 13, 2014

Today's Goal

Task 1.2 Critical Project Review (CPR) Meetings

- The goal of this task is to ***determine if the project should continue*** to receive Energy Commission funding to complete this Agreement and to ***identify any needed modifications*** to the tasks, products, schedule, or budget.

We should continue
There are needed modifications

Agenda

- Overview (Jim)
  – CES CPV Technology
  – Project Scope & Status
- Task 2 (Paul)
- Tasks 3-4 (Jim)
- Task 5 (Jim)
- Discussion (All)

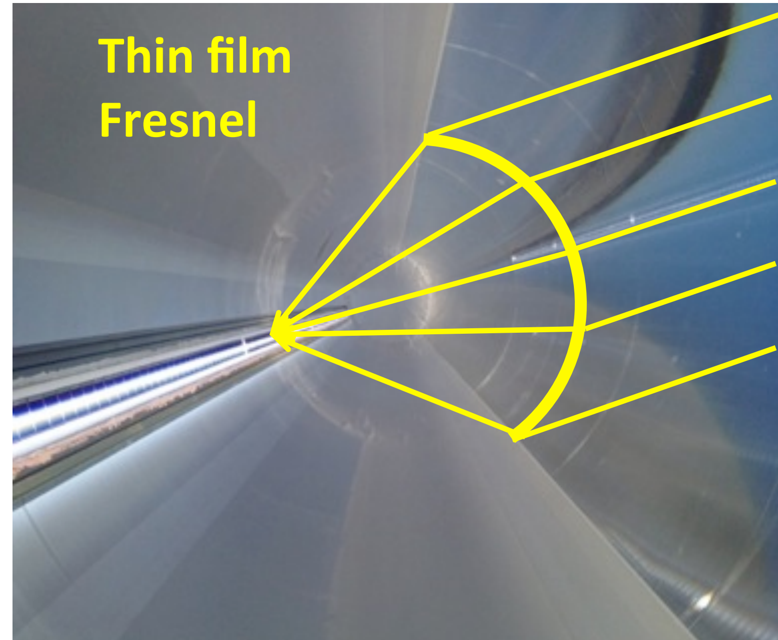
Cool Earth Solar

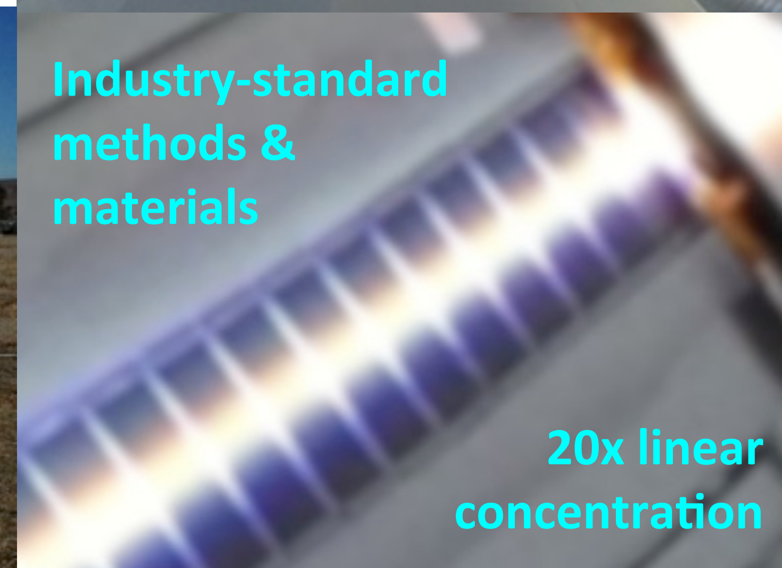
Medium Concentration PhotoVoltaics

Cool Earth Solar CPV Concentrator

Unique inflated concentrator module

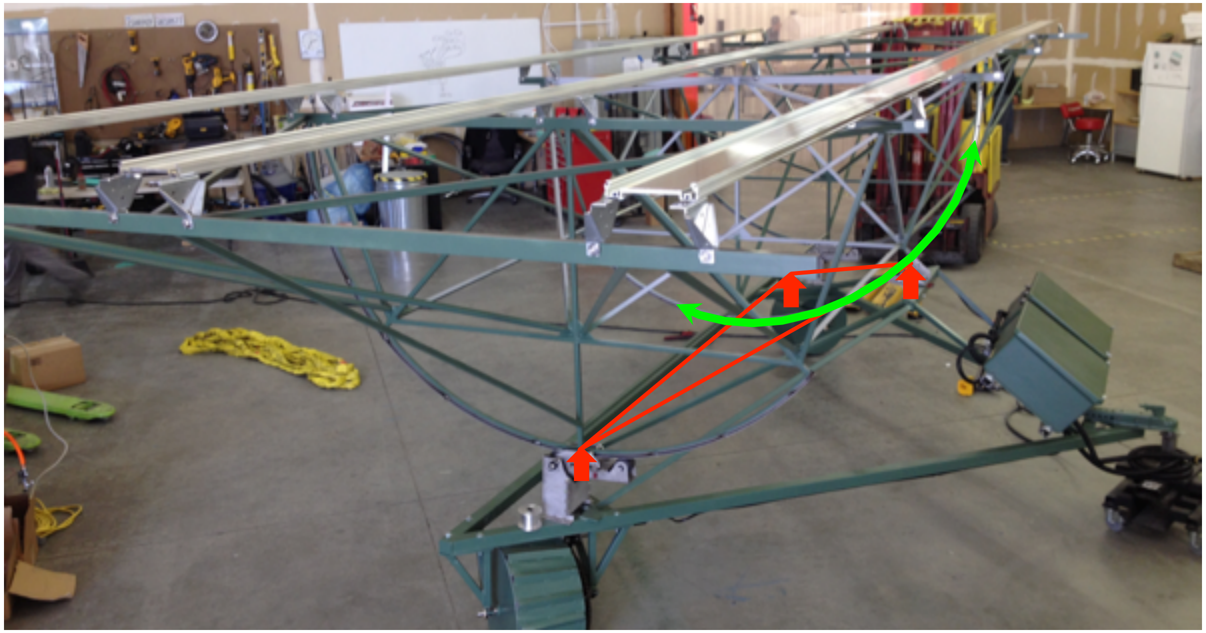
- Half the module \$/W of flat panel in 2016
- Best in class utility-scale cost of energy
- High volume design, US supply chain
- ***Very low capex requirements***





Highly Reliable 2-axis Tracking at 1-axis cost

Enabled by low weight thin film optic



Single-board local SCADA

- Closed loop tracking
- High volume, low cost

Roll on ground design

- Ground screw at axis
- Rapid, low cost install

Open frame construction

- Easily adapted to high volume mfg
- High strength/weight ratio

Low cost actuation

- Support separate from movement
- Leverage advantage

Industry Standard Materials & Methods

Scalable by Design

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- Fresnel Optic ← Reflective highway signs
- Tubes ← Agricultural bags, sheeting
- Receiver ← Solar-qualified films, cells
- Frame ← Automotive industry
- Actuators ← Automotive industry
- SCADA ← Standard high-volume electronics

Repurpose existing US manufacturing capacity
"Fabless", "Scale by PO"

Capital Avoidance Strategy

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Key design principle: Re-purpose existing manufacturing capacity

- Flexible, responsive
- Avoids major capital investment risk points
- Capacity available in large supply in the US

Match production capacity to market pull

- Organic growth when market is weak
  - Slower, supported by internal cash, resources
- Rapid exponential growth in response to demand
  - No capital expansion, "small" cash infusions for tooling, fixtures, and manufacturing engineering

Market pull is here

Cool Earth Solar has a Secure Future

A good story with great potential

Exclusive solar energy supplier to D'Arcinoff Group Energy: 265 MW by 2016

- Project margins used to continue funding of CPV development
- Deploy CPV systems to DGE
- Initial market pull from DGE is larger than we can fulfill with CPV alone

Project Overview

Tasks & Spending

Project Objective

Executive Summary and Narrative

Project objective:

- **Develop, demonstrate, and disseminate** a reproducible model for integrating more **solar generation** into a **community** while enhancing grid stability and overall system efficiency.

Project Description

- The project partners seek to develop, build, and demonstrate an integrated renewable solution for the Livermore Valley Open Campus (LVOC) community. The project will integrate three components:
  - 1**. CPV technology**: An innovative, low cost, community-scale concentrated photovoltaic system
  - 2. **Solar forecasting**: A localized, high temporal resolution forecast of the community-scale CPV installation's generation and of the solar resource
  - 3. **Building energy management** for improved efficiency and peak load shaving: The CPV technology and the solar forecast will be combined with smart building technology to optimize operation of a building, shaving peak load and improving overall energy efficiency

Sandia National Laboratories

Energy, Climate, & Infrastructure Security

Sandia's Livermore Site to Help Validate Cool Earth Solar's CPV Technology

Sandia and Cool Earth Solar (CES) are collaborating to install a five-acre array of their innovative concentrating photovoltaic (CPV) technology at Sandia's Livermore Valley Open Campus (LVOC) site—providing LVOC with electricity and CES with long-term performance-validation data.

Working Together

Sandia and Cool Earth Solar (CES) have signed a cooperative research

renewable energy adoption. This Sandia-CES CRADA is another avenue in the Labs' efforts to support DOE in

Task Summary

	Task	Total Billed this Invoice	Total Previously Billed	Billed to Date	Budget Amt.
1.0	Administration	13,442.10	153,917.50	167,359.60	191,796.00
2.0	Install and Operate 100KW of CPV Arrays				652,872.00
3.0	Deploy Networked Array Of Sky Imagers				98,633.00
4.0	Develop Test and Demonstrate Sola Power Forecast Model	[illegible]		[illegible]	514,202.00
5.0	Optimize Building Energy Management Using Environmental Forecasts				229,430.00
6.0	Outreach		-	-	17,343.00
7.0	Technology Transfer Activites		-	-	11,081.00
8.0	Production Readiness Plan		-	-	11,081.00

Deploy CES CPV collectors

Sky imaging & solar power forecasting

Smart building management

Delayed Start Issue
Time lost before we began

- Project kick-off delayed three months from agreement schedule
  - Largest impact was on Task 2 customer-sourced matching funds
    - Progress with customer dependent on product maturity as demonstrated by under-sun performance. This important milestone was achieved in June.

- Initial funding to CES delayed an additional two months
  - Largest impact to Task 4 (LLNL) subcontractor tasks
    - Subcontractor's rules require prepaid funding for *any* work performed by tech team, including planning. Kick-off meetings were unproductive (no preparation or follow-up allowed). No plan available to justify spending. Delays caused significant concerns from subcontractor regarding viability of timeline and deliverables.

CPV Deployments

Task 2

CPV Deployment Task

	Summary Task Budget	Prime Recipient Re... Co... Inc	Major Subcontractor #1 ...ble ... Livermore	Commission Reimbursable Costs	Match Funding	Totals
1.0	Administration	$ 191,796		$ 191,796	$ 118,084	$ 309,880
2.0	Install and Operate 100kW of Cool Earth Solar CPV Arrays	$ 652,872		$ 652,872	$ 650,314	$ 1,303,186
3.0	Deploy Networked Array of Cool Earth Solar Sky Imagers	$ 98,633		$ 98,633	$ 218,397	$ 317,030
4.0	Develop, Test, and Demonstrate Solar Power Forecast Model		[illegible]	...202	$ -	$ 514,202
5.0	Optimize Building Energy Management Using Environmental Forecasts	$ 50,...	[illegible]	...430	$ -	$ 229,430
6.0	Outreach	$ 17,343		$ 17,343	$ 16,865	$ 34,208
7.0	Technology Transfer Activities	$ 11,081		$ 11,081	$ 11,081	$ 22,162
8.0	Production Readiness Plan	$ 11,081		$ 11,081	$ 11,081	$ 22,162
	Grand Totals	$ 1,032,806	$ 693,632	$ 1,726,438	$ 1,025,822	$ 2,752,260

Mainly 10kW focused

Mainly focused on balance of 100kW

Task 2: Overview

- To demonstrate that a solar technology can succeed in the marketplace, three prerequisites must be met
  - The technology can be permitted and operated safely in an unattended environment
  - The technology must work (create predictable energy that can be integrated into the grid)
  - The technology must attract commercial interest from customers
    - Esp. customers that can assist in project finance and performance warranties

Task 2: From Brownfield to Operating Solar Site

Image of Sandia site prior to installation with annotations for operations

Image of Sandia site permitted and ready for operations

Cool Earth has demonstrated the ability to permit (CEQA) and operate in California

Task 2: 10kW Deployment
Execution progressing as expected

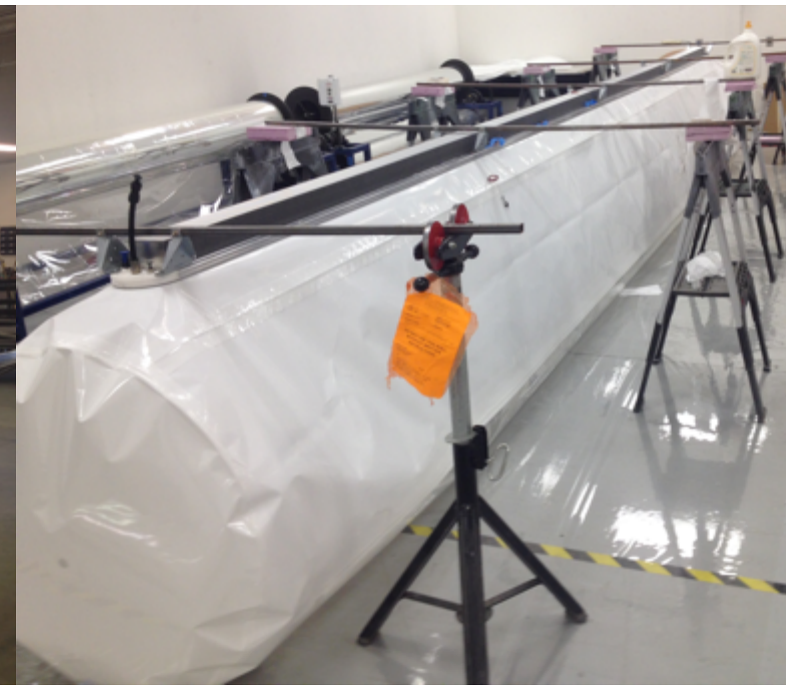
- Relative progress ahead of original estimates
  - Approximately three months regained
  - Physical deployments back-loaded in schedule

No further risk to overall project schedule

Task 2: 10kW Deployment, cont'd

Execution progressing as expected

- Frames to complete first 10kW welded and in house
- Module construction and deployment continues



No further risk to overall project schedule

Task 2: Demonstrating the Technology works

One tube module (810W_{DC} STC), June 2014

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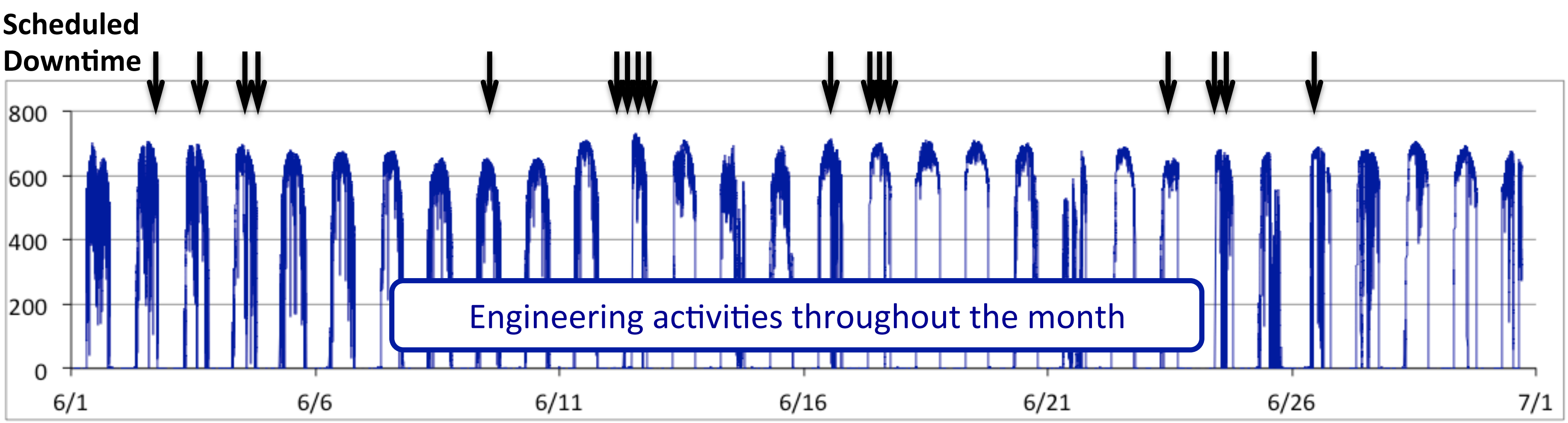
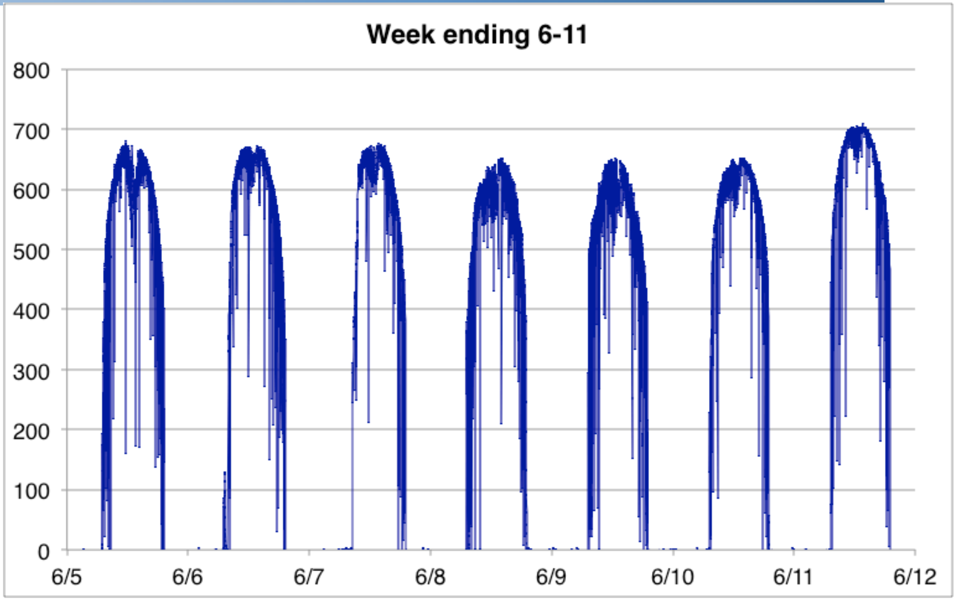
Total Energy	191 kWh_{DC}
• *Average per day*	*6.37 kWh_{DC}*
Availability (DNI)	90%
• *Conservative late start, early stow*	
• *No unscheduled downtime*	
Performance Ratio	77.8%
• *Includes scheduled downtime*	

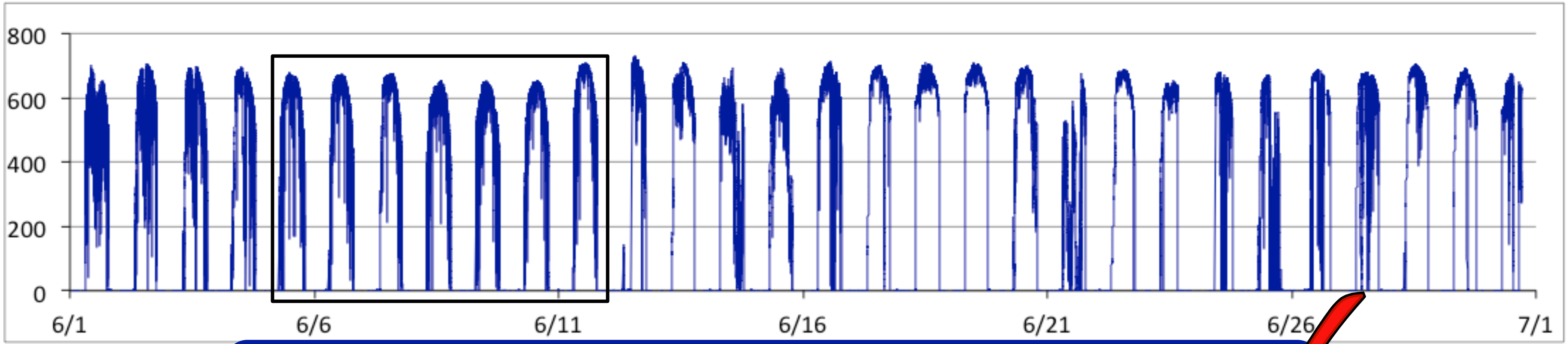


Best Weekly Performance in June

Week ending 6-11

Total Energy	49.6 kWh_{DC}
• *Average per day*	*7.08* kWh_{DC}
Performance Ratio	83.8%





The technology works in an operational environment

Task 2 Next Steps: 100kW CPV Deployment

- Cool Earth Solar has an exclusive contract to deliver 265 MW solar power to "behind the meter" industrial project
- Expect signed agreement with strategic partner in August
  - Includes 100kW CPV shipments to Sandia and customer site
  - Additional committed CPV shipments (beyond 100kW) in 2016
- Customer-driven timeline
  - Anticipate additional 10kW at Sandia by March 2015
  - Balance of 100kW shipments throughout 2015

Commercialization path to success

Task 2: Conclusions about CPV Deployments

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- CES has demonstrated the ability to permit (CEQA) and operate this innovate technology in CA
- CES has demonstrated that the technology works in an operational environment
- CES has used these two CEC-funded prerequisites, to attract and gain commitments for >100 kW deployment from a commercial customer.

Goal of introducing novel solar tech achieved

Task 2 Scope Change Request

- We expect to have 20kW installed by March 2015
  - Substantially short of 100kW total goal

- Option 1: Continue under current terms
  - CEC project deliverable will not be met
  - CES technology is a commercial success
- **Option 2: Change scope to 20kW**
  - **80% reduction in expectations due to timeline slip (late start)**
  - **CES technology is a commercial success**
  - **Project is also a success**

CES recommends Option 2

Solar Forecasting

Tasks 3 & 4

Meteorology Forecasting Tasks

	Summary Task Budget	Prime Recipient Reimbursable Costs	Major Subcontractor #1 Reimbursable Costs	Commission Reimbursable Costs	Match Funding	Totals
		Cool Earth Solar,	Lawrence [illegible]more			
1.0	Administration	[illegible]	[illegible]	$ 191,796	$ 118,084	$ 309,880
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4.0	Develop, Test, and Demonstrate Solar Power Forecast Model		$ 514,202	$ 514,202	$ -	$ 514,202
5.0	Optimize Building Energy Management Using Environmental Forecasts	$ 50,000	$ 179,430	$ 229,430	$ -	$ 229,430
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	Grand Totals	$ 1,032,806	$ 693,632	$ 1,726,438	$ 1,025,822	$ 2,752,260

20% Spent overall

Tasks 3/4: Plan Overtaken by Events

The proposed meteorology tech is not unique

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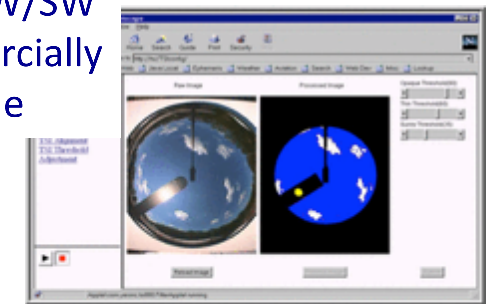
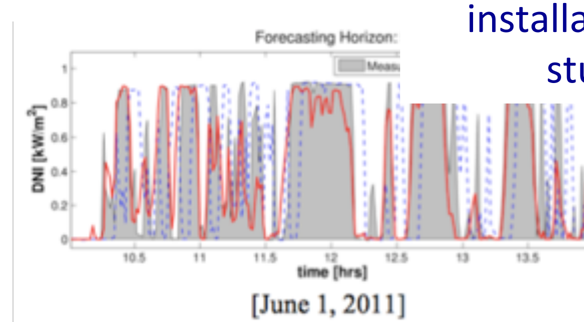
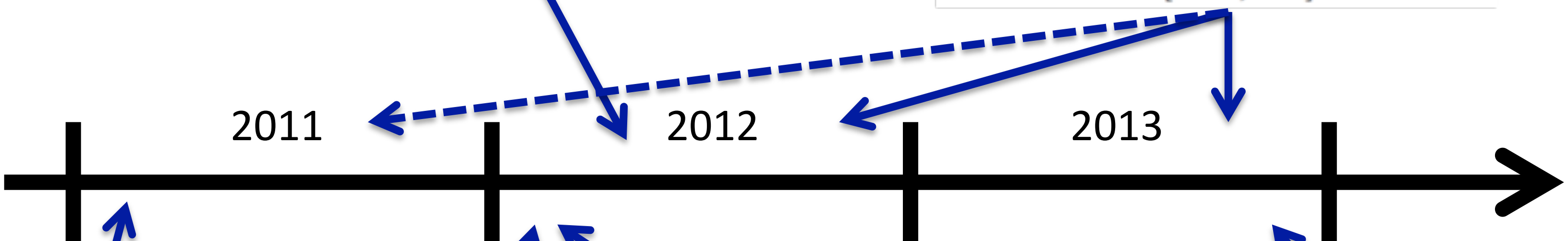
Adv. HW/SW commercially available



Multiple field installations studied



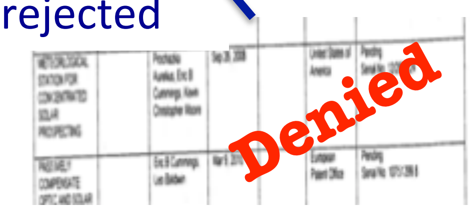


Cool Earth Solar launches internal metrology effort, receives PIER grant

Cool Earth Solar completes grant, ends metrology development

CEC grant submission prepared

Cool Earth Solar patent rejected



Task 3 & 4 Scope Change Options

- Option 1: Continue current plan
- Option 2: “Compound Eye”
  - Use existing optical sensors on CES 2D trackers
  - Use computational optics to obtain cross-sectional cloud information
- Option 3: “Modified Carlos”
  - Install multiple sky imagers
  - Use image tracking/correlations
- Option 4: Cancel tasks 3 & 4

Synthetic Aperture Optical Sensing for Predicting Solar Resource

Using existing solar collectors as multi-aperture sensors to image clouds

Cool Earth Solar

August 2014

Solar Energy Forecasting Value

Making solar robust against clouds

Sudden loss of large amounts of power characteristic of utility-scale solar

- Community-scale distributed generation is tolerant of partial shading
- Distribution averages cloud risk

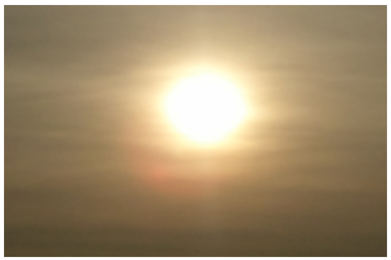
Power portfolio management

- Critical response time is 30 min – 3 hrs
  - Response time for changing load or generation
  - 10 MW/min ramp rate, start/stop cycle = hours
- Predict averaged solar power across grid

Solar DNI Challenge

What is a cloud? The case for 3D imaging






- "Cloud" = any atmospheric scattering that reduces DNI
  - Losses of DNI are more nuanced than all-or-nothing shading from an optically-thick cloud
- Diffusivity/scattering highly variable
  - Penetration depth varies by orders of magnitude
  - Position variant (winds aloft)
  - Time variant (evaporation/condensation)

Clouds Scatter Light

Transmission and reflection are inadequate descriptors

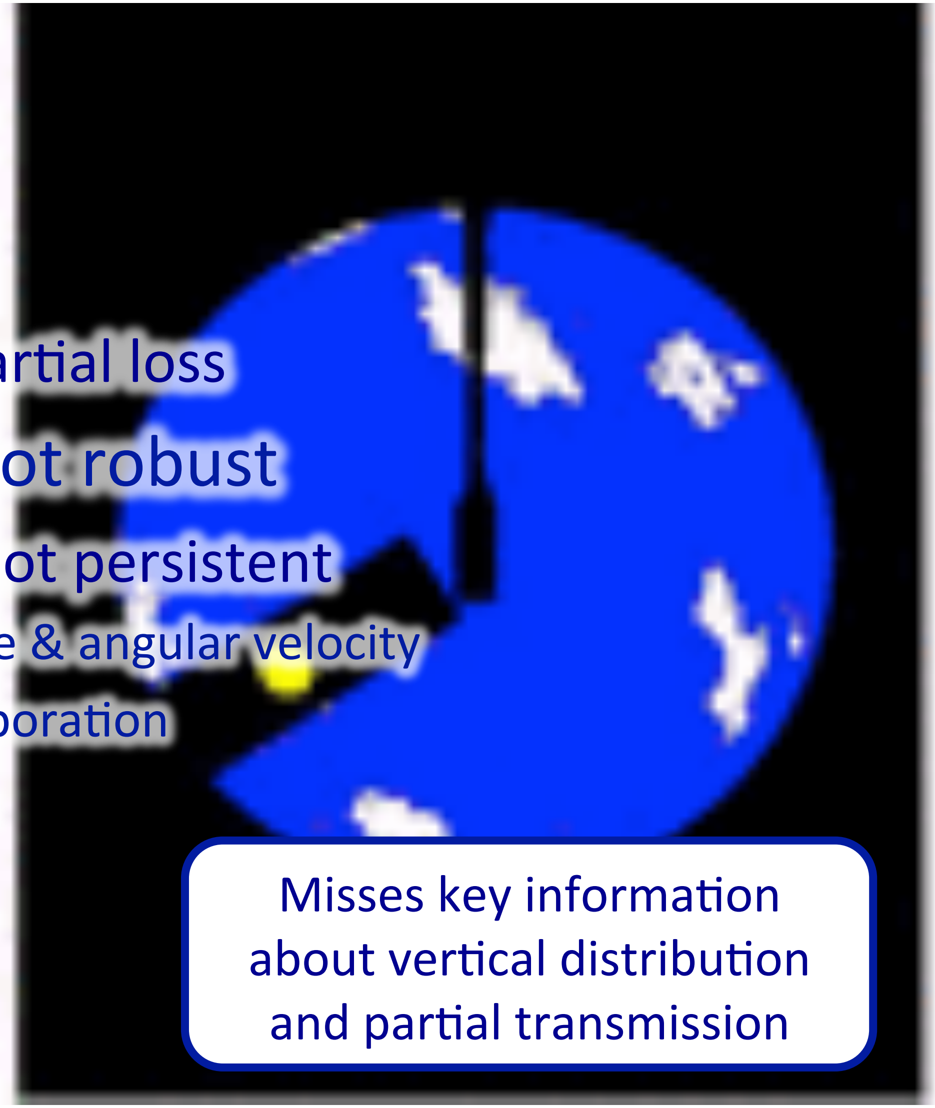
- Observed signal comes from total integrated light scattered into the viewing angle

- Solar DNI is reduced by the total integrated light scattered out of the viewing angle

3D information is critical for understanding solar resource

Typical Sky Imager Efforts in 2D

Assumptions make things easier, but eliminate crucial detail



- Binary pixels
  - Cloud, Not-Cloud
  - No grayscale, no partial loss
- Object tracking is not robust
  - Cloud objects are not persistent
    - Variation in altitude & angular velocity
    - Condensation/evaporation

Misses key information about vertical distribution and partial transmission

Possible Solution: Synthetic Apertures

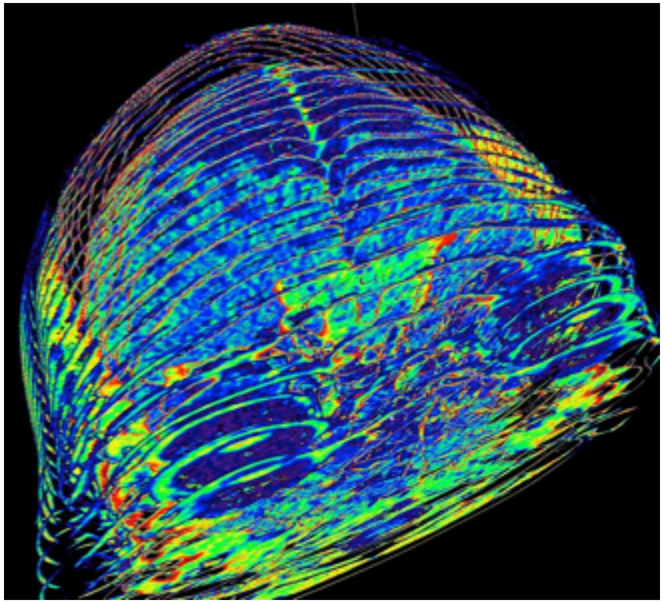
- Use each collector as a unique aperture
  - CES CPV, single point, pointable, multiple independent rigs
  - Can be whole-sky, single bit (flat panel)

- Can enough simple sensors, widely distributed, be fused to provide useful information?

Computational Optics are in Wide Use

Mathematical techniques are well known

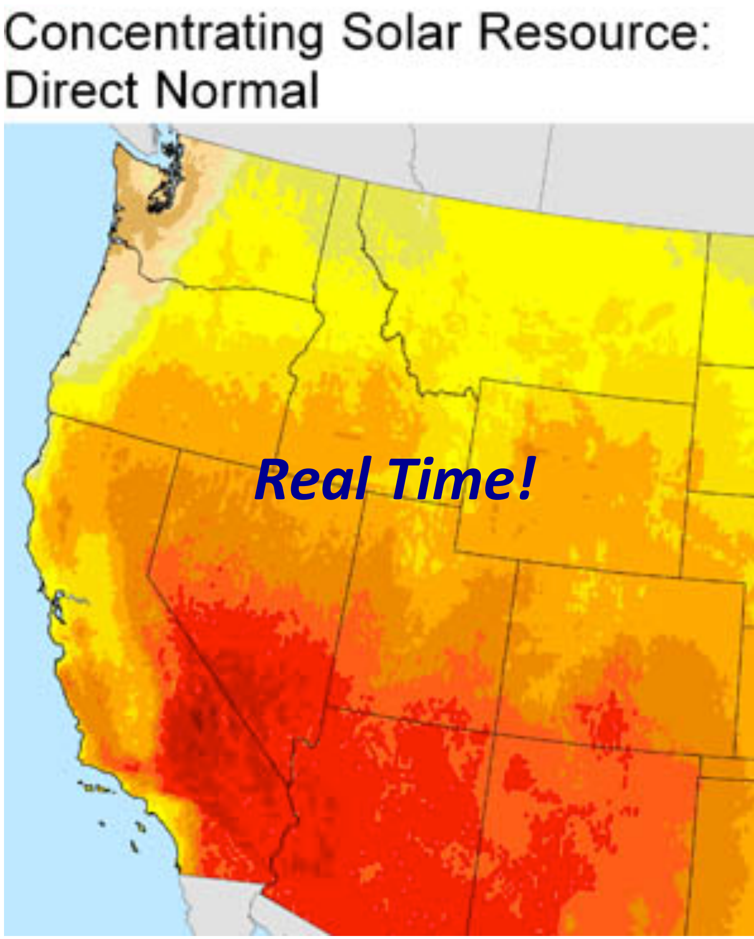
- Familiar tomographic medical applications
  - Highly scattering medium
  - Non-invasive/remote
- Synthetic Aperture
  - "Bullet time" from the Matrix
  - ESPN Axis
- Specific weather-related applications
  - GPS signals for atmospheric mapping
  - Acoustic signals for wind speed, air temperature
  - Synthetic aperture radar



Vision: Solar Panopticon

Every solar collector is also a solar sensor

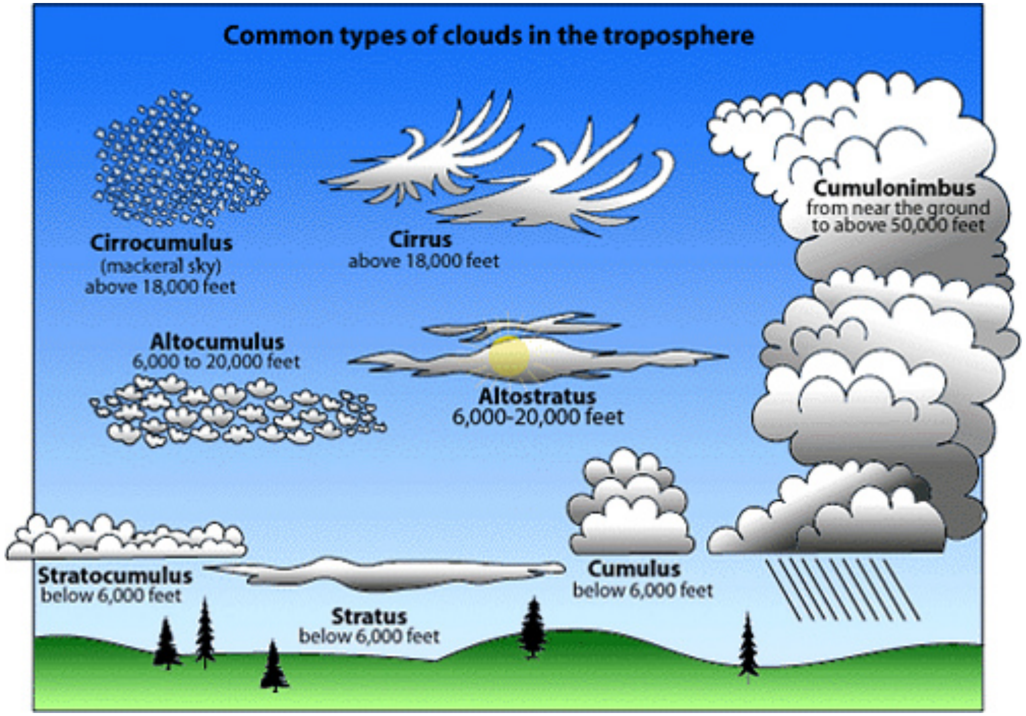
- Data fusion techniques can combine data from arbitrary numbers and locations of sensors
  - Area coverage and resolution will vary with sensor coverage
    - Trend is headed for significant distributed generation
  - Advantage: numbers and sites
    - Better than high resolution sensors far apart
  - Disadvantage: sensing is secondary to energy collection
    - Can this work with no HW mods required?



What are we trying to see?

Typical cloud height

- Stratus moisture decks (0-6500’, 0-1500’ thick decks)
  - *E.g. 1000, 3000, 5000*
- Cumulus convective cells (2000-35000’)
- Alto-x (6500-16500’)
  - *E.g. 10000*
- Cirrus (>16500’)
  - *E.g. 20000*

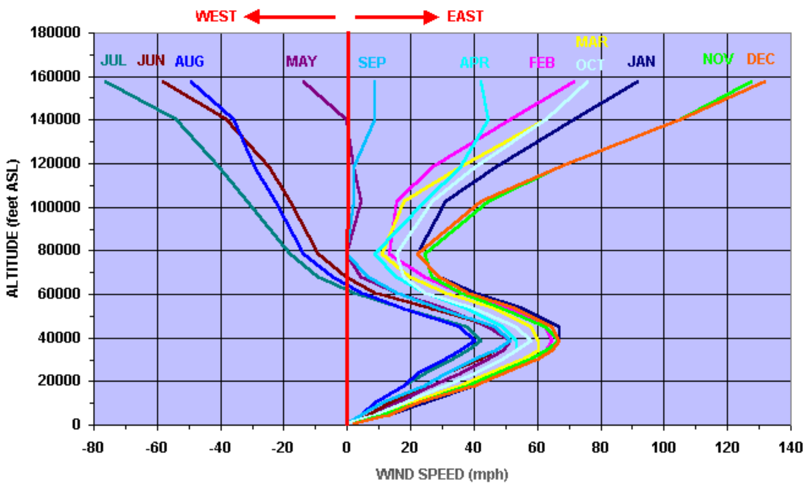


When are we trying to see it?

On average, how far away is 30 minutes? What angle?

- Average wind speeds in the troposphere are roughly proportional to height

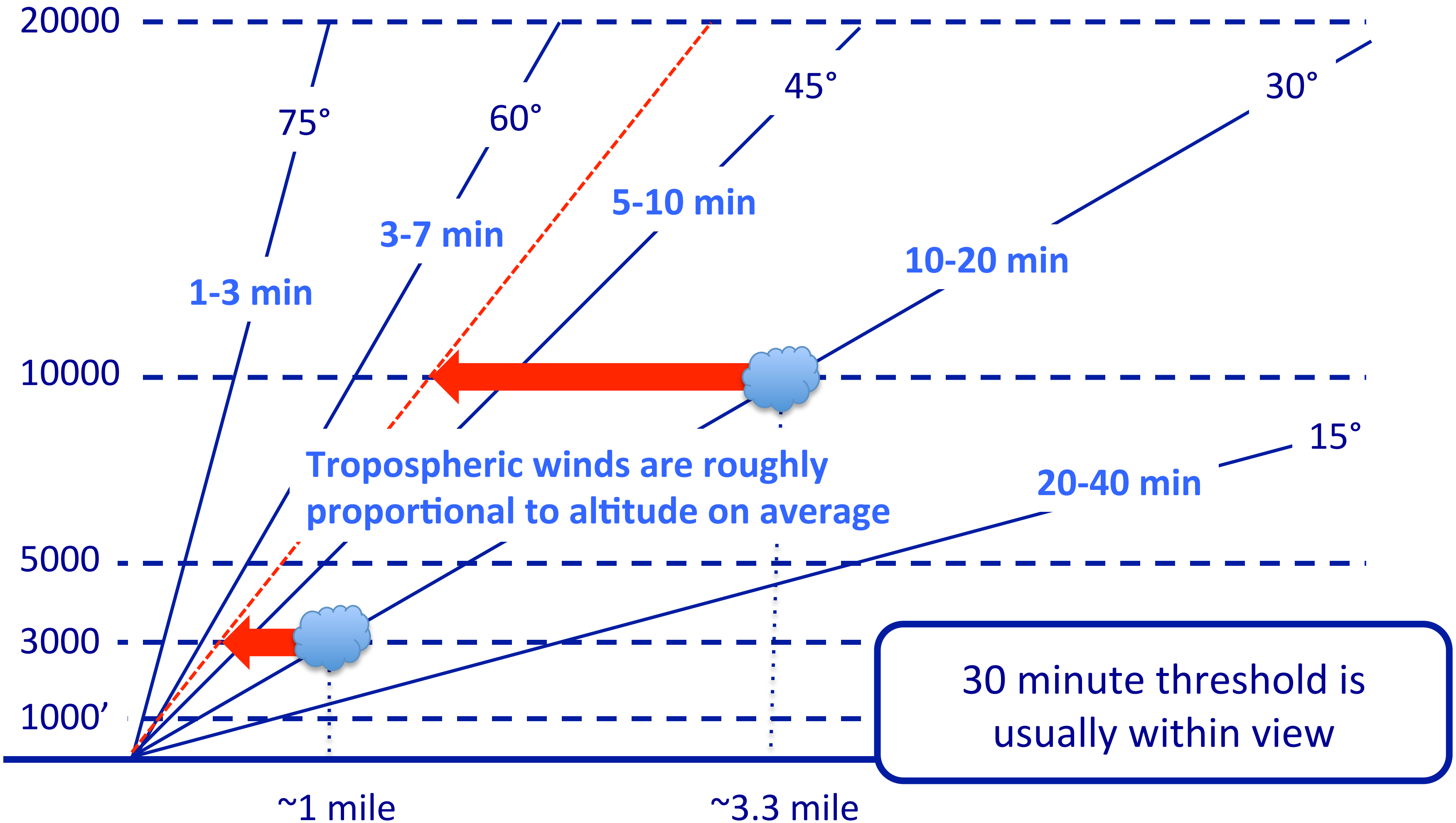
- Angular velocity roughly independent of height



Altitude	Low	High
20000	20	45
10000	10	23
5000	5	11
3000	3	7
1000	1	2

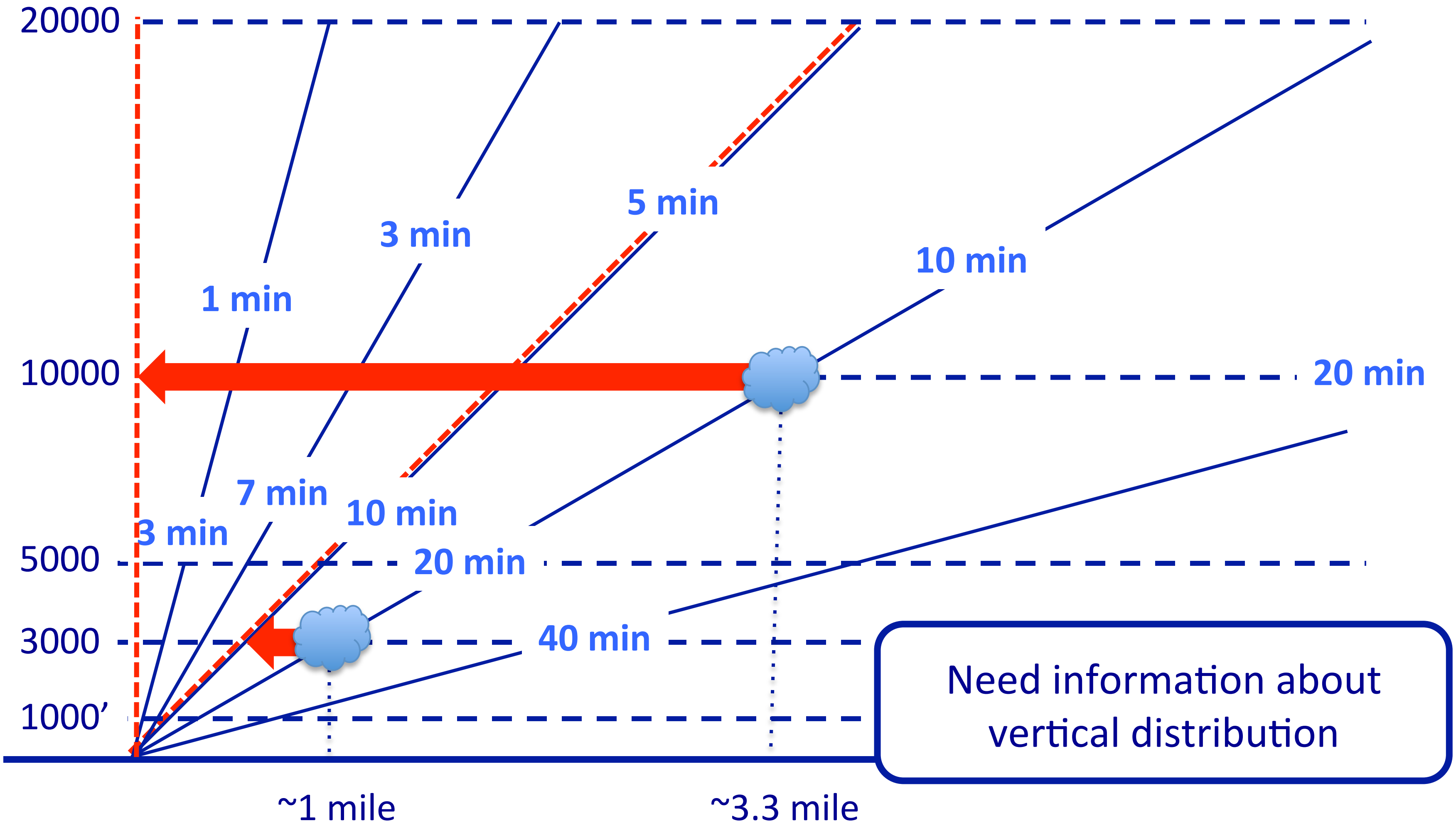
Angles and Distances

Rate of angular movement is "constant" independent of height



Non-proportional Winds Aloft

Rate (& direction) of angular movement sometimes depends on height



Feasibility Question

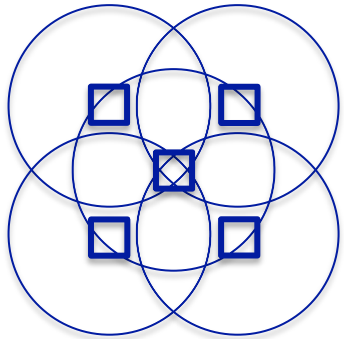
- Will Computational Optics using simple solar collectors provide imaging information useful for solar prediction?

- Step 1: Can an unmodified CES rig “see”?
  - FTM module
  - Power collection tubes
- Step 2: Can two CES rigs provide vertical information about a cloud?

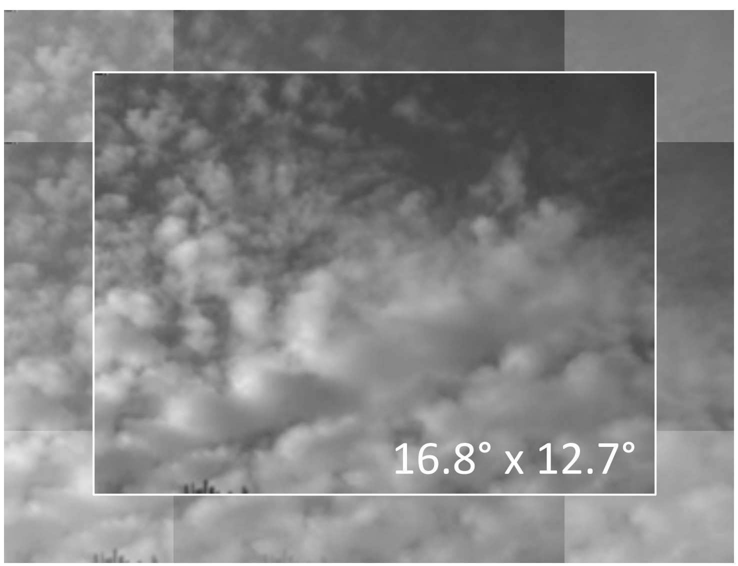
Simulated Unmodified FTM Imaging

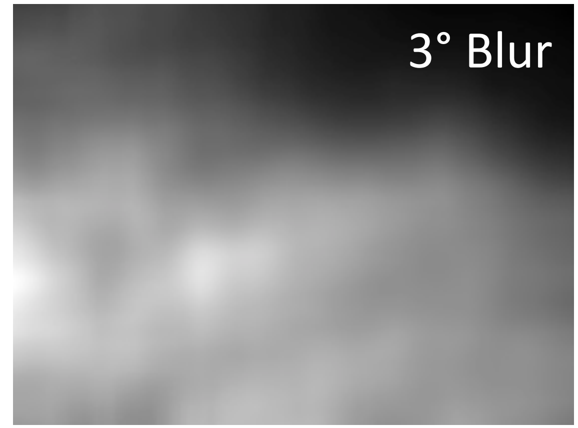
Fusion of five solar-edge detection sensors

Fine-Track Module consists of a five sensor pattern

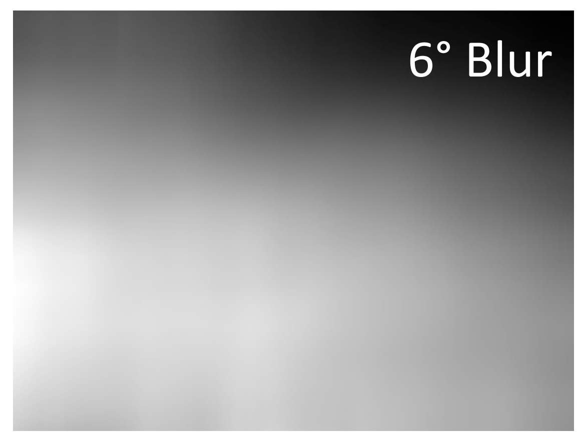


Hi Res Original



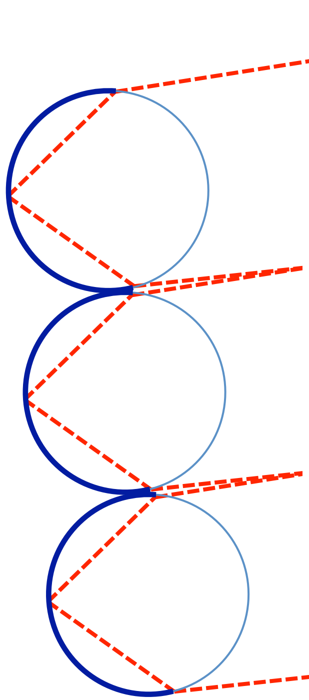


10° viewing angle improved to 3-6° through 5x synthetic aperture



Using Power Collection Tubes

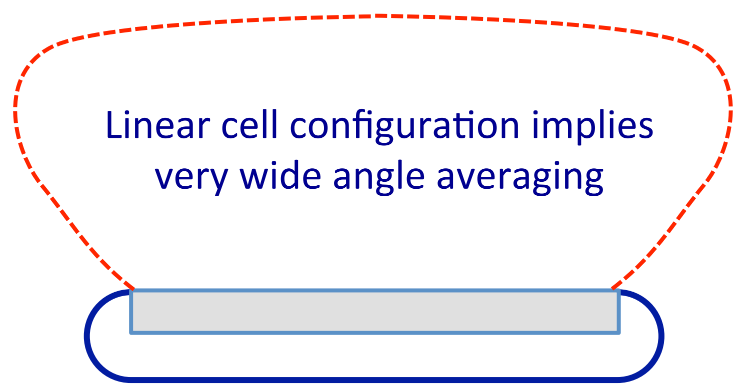
Linear configuration tradeoff



- 20x Magnification narrows elevation field of view
- 3x vertical sensor fusion
- Greatly increased light collection

Enhanced vertical resolution

Averaged horizontal signal



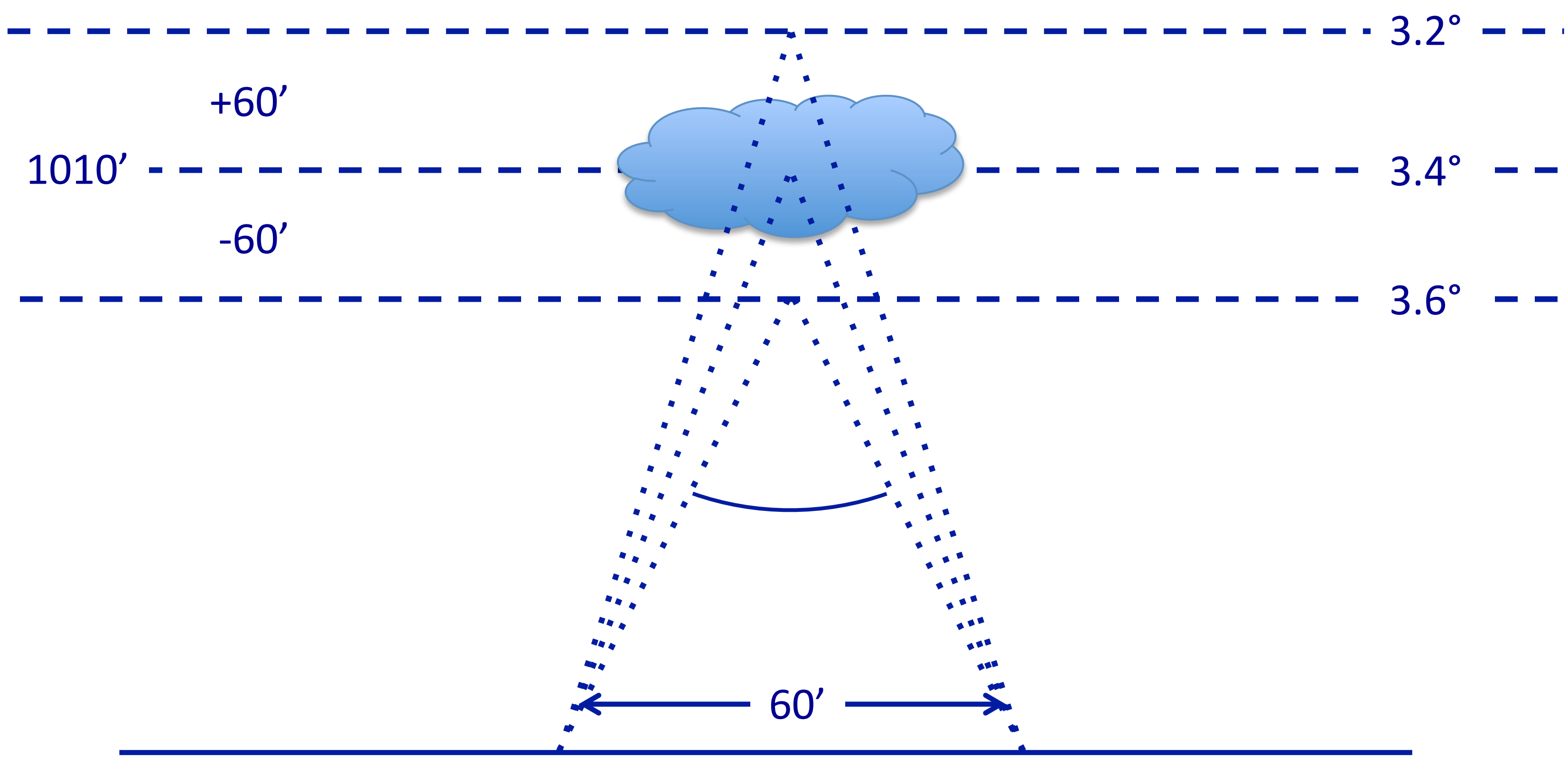
Practical Issue

- Computations require sufficient separation of viewing angle (orthogonality)
  - Predrilled ground screws allow 60’ separation
  - Ineffective for long distances

- Perform initial testing on closer clouds
  - 60-75° scanning would result in tractable parallax for low clouds
  - Larger installations or multiple fields would allow resolution for up to 40 min lead time

Depth Perception Error Propagation

Sandia rig spacing 60 feet



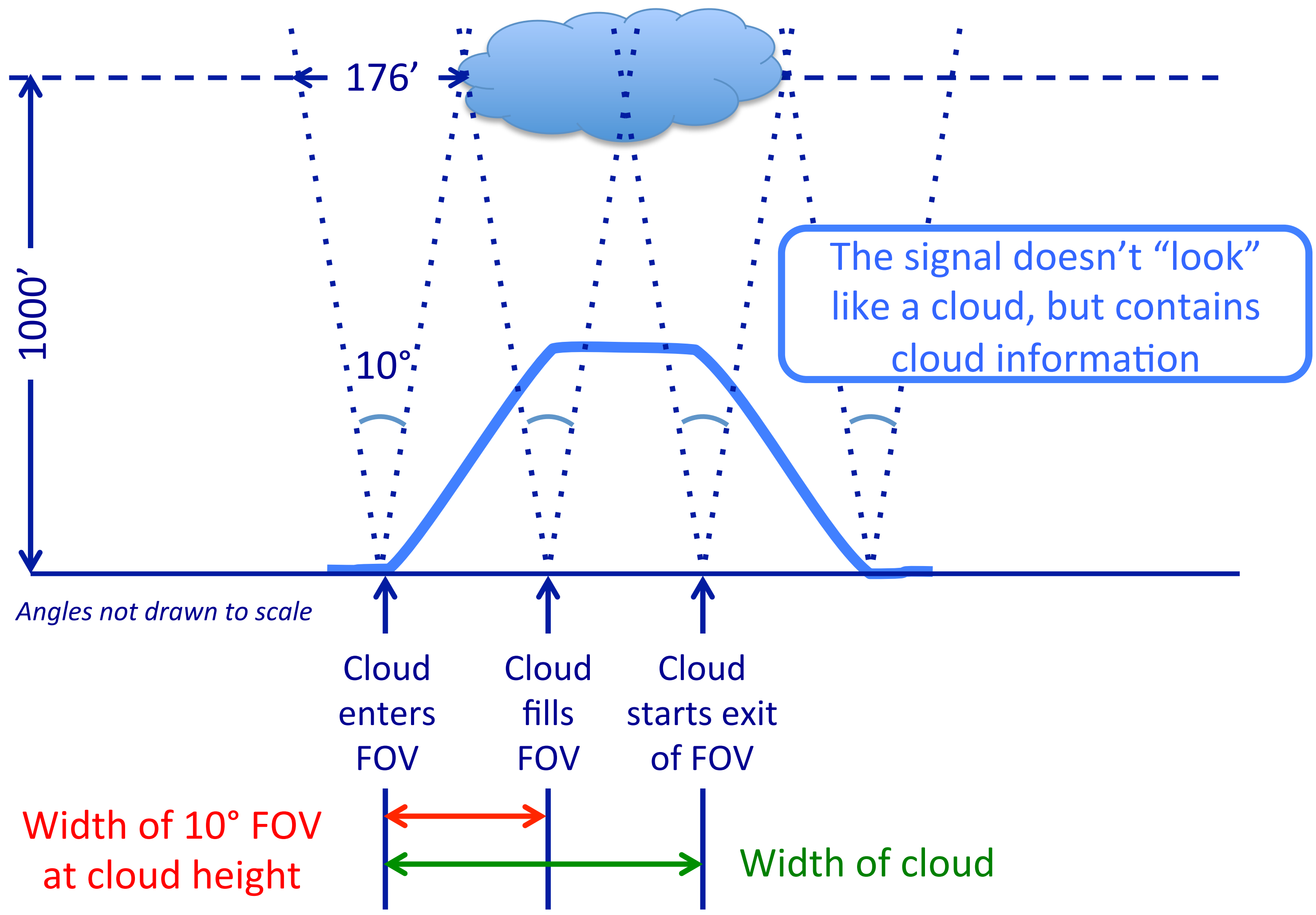
Angles not drawn to scale

Spacing sufficient for low resolution image of low clouds

Deconvolving position-based information

Linear translation of wide-field sensor

(Same as moving cloud, stationary sensor)



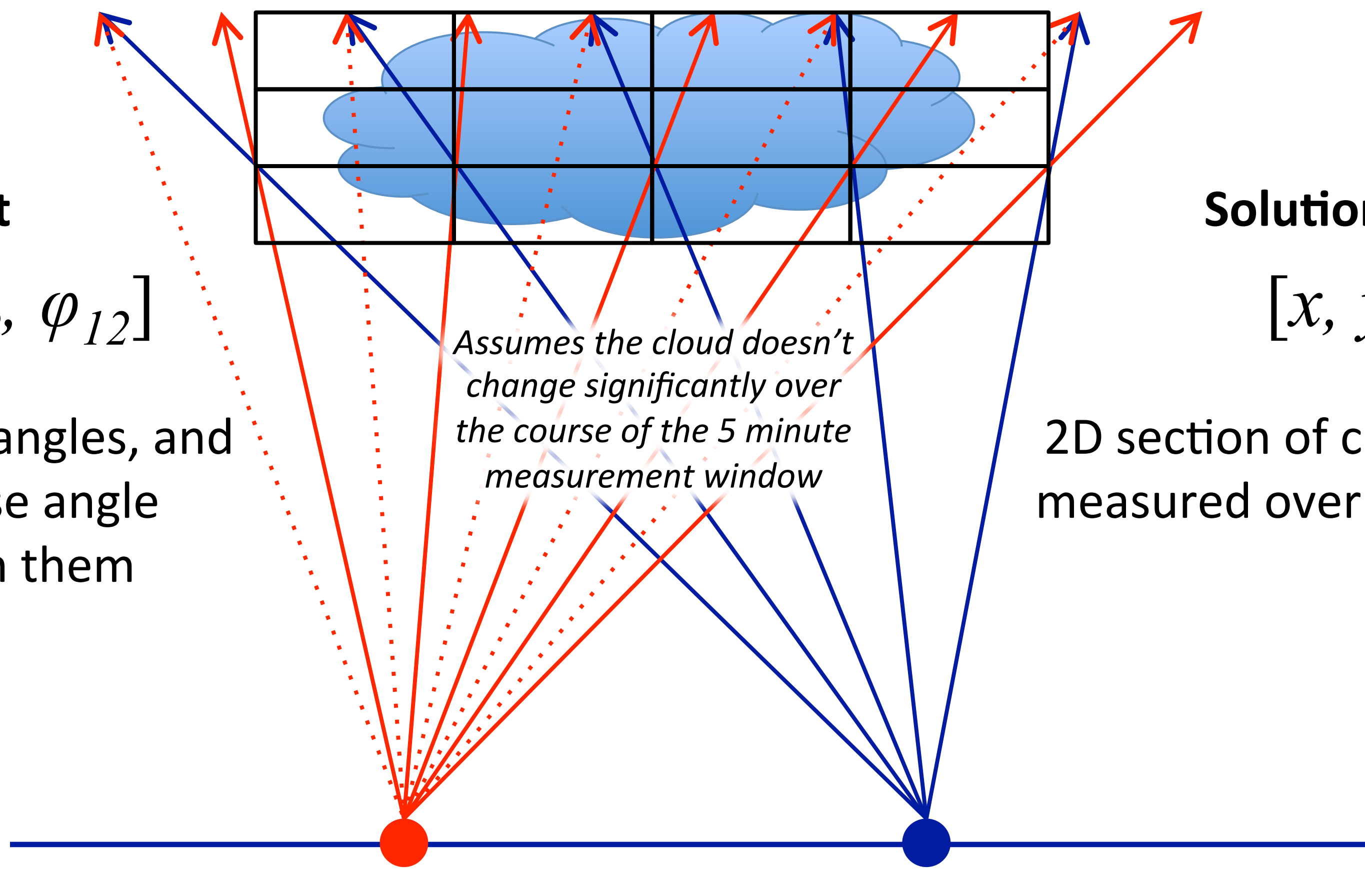
Coplanar Scanning for 2D Section of Cloud

Obtain height information from phase/time-shifted correlations

Basis Set

$[\theta_1, \theta_2, \varphi_{12}]$

Two rig angles, and the phase angle between them



Solution Set

$[x, y, t]$

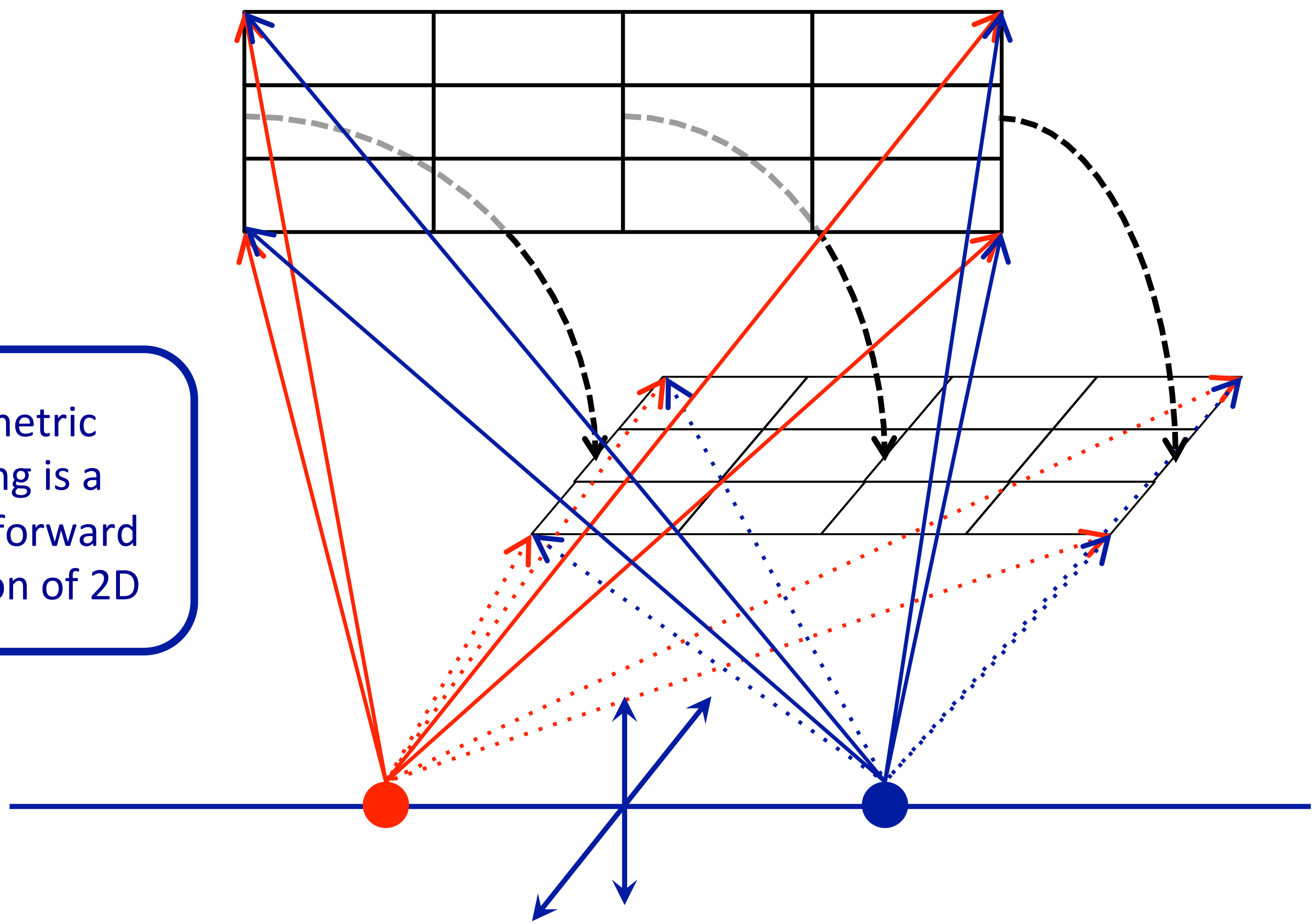
2D section of cloud, measured over time

2D experiment provides proof of concept for scanning volumes

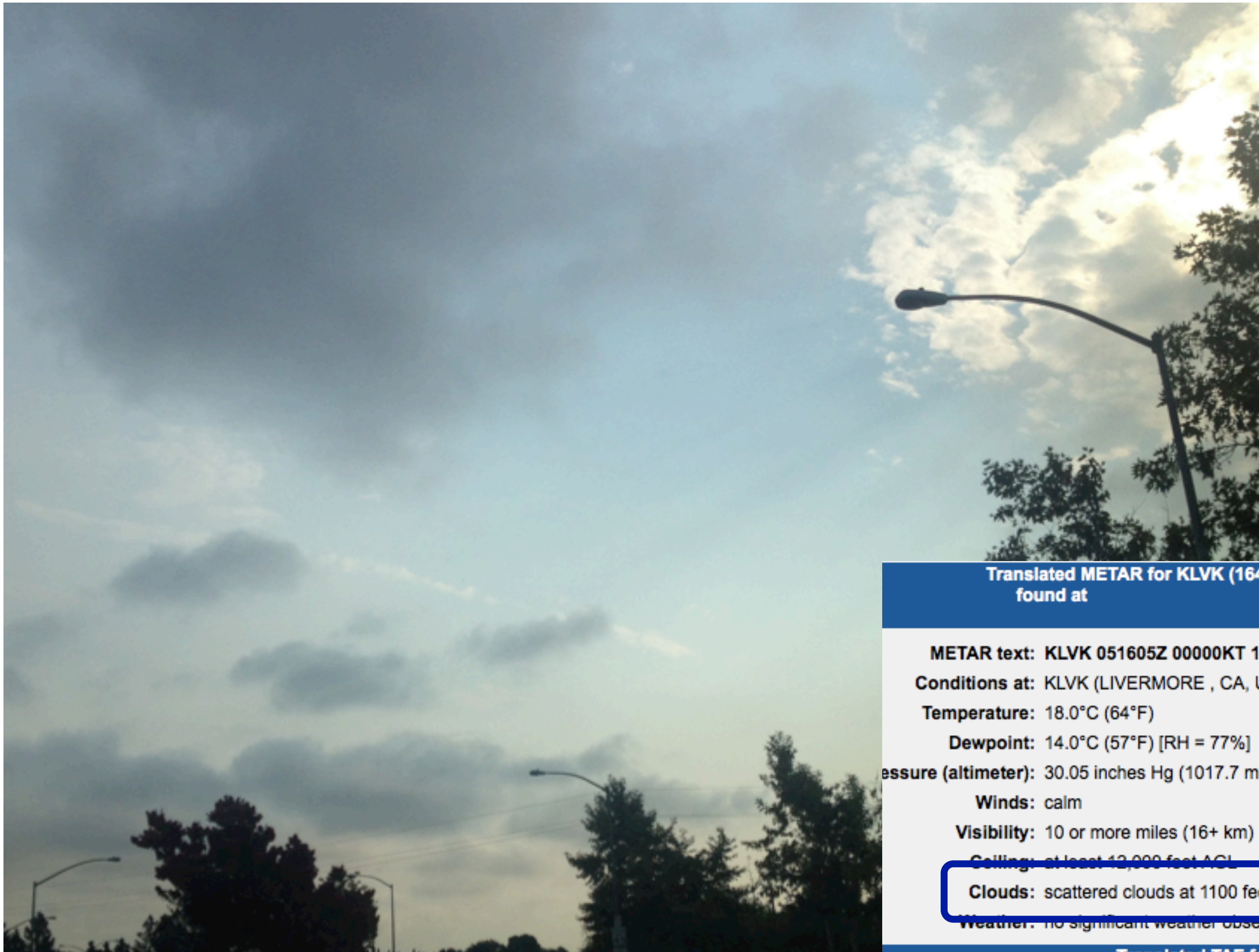
3D imaging

Add more angles

Volumetric imaging is a straightforward extension of 2D



Candidate Clouds for Study



Translated METAR for KLVK (1640 UTC 05 August 2014) found at

METAR text:	**KLVK 051605Z 00000KT 10SM SCT011 18/14 A3005 RMK AO2**
Conditions at:	KLVK (LIVERMORE , CA, US) observed 1605 UTC 05 August 20
Temperature:	18.0°C (64°F)
Dewpoint:	14.0°C (57°F) [RH = 77%]
essure (altimeter):	30.05 inches Hg (1017.7 mb)
Winds:	calm
Visibility:	10 or more miles (16+ km)
Ceiling:	at least 12,000 feet AGL
Clouds:	$\boxed{\text{scattered clouds at 1100 feet AGL}}$
Weather:	no significant weather observed at this time

Translated TAF for KLVK

“Compound Eye” Schedule

Aug/14	Sept	Oct	Nov	Dec	Jan/15	Feb	March	Apr	May
1. CPR/ Tasks, etc.									
2. Can unmodified rig “see”?									
FTM communicate									
	Collector tubes								
			3. Can Two CES Rigs Provide Vertical Info?						
			Two trackers, two FTM’s						
					Expts., Data Analysis and write-up				

"Compound Eye" Spending Roll-up

coolearth

Task	Subtask/Question	Estimate(k)	Comment
1. Tasks/ agreement	Proposal, Go at CPR, modification docs	50	Background work begun, CPR today, agreement to follow.
2. Can unmodified rig "see"?			
	FTM Communicate	140	Field comm infrastructure upgrades \$25K, Firmware/software to complete signals \$50K, Physical hardware implement \$15K, FTM eval. \$15K, Data collection \$20K, re-spin debug \$15K
	Collector Tubes	70	Custom receiver hardware with expts. \$20K, fabrication \$20K, Software for track \$10K, experiments and analysis \$20K.
3. Can two CES rigs provide vertical info?			
	Two trackers, two FTMs	70	Hardware for 2nd FTM plus labor \$30K, Re-spin custom receiver \$10K, 3 custom receivers \$30K
	Experiments, Data Analysis and write-up	80	Labor, computation, analysis, and write-up.
Sum		~450	+ 40K project management/admin.

Can be completed within existing budget

Task 3 & 4 Scope Change Options

- Option 1: Continue current plan
  - Duplicates previous work at great cost
- **Option 2: “Compound Eye”**
  - **Achievable task given remaining timeline**
  - **Novel possibility of measuring vertical depth, partial transmission**
- Option 3: “Modified Carlos”
  - Installed equipment used primarily for project, then mothballed
  - Follows well-trodden approach (lower risk, less interesting)
- Option 4: Cancel both tasks

CES recommends Option 2

Smart Buildings

Task 5

Smart Building Management Task

	Summary Task Budget	Prime Recipient Reimbursable Costs Cool Earth Solar, Inc	Major Subcontractor #1 Reimbursable Costs Lawrence Livermore	Commission Reimbursable Costs	Match Funding	Totals
1.0	Administration	$ 191,796		**$ 191,796**	**$ 118,084**	**$ 309,880**
2.0	Install and Operate 100kW of Cool Earth Solar CPV Arrays	$ 652,872		**$ 652,872**	**$ 650,314**	**$ 1,303,186**
3.0	Deploy Networked Array of Cool Earth Solar Sky Imagers	$ 98,633		**$ 98,633**	**$ 218,397**	**$ 317,030**
4.0	Develop, Test, and Demonstrate Solar Power Forecast Model		$ 514,202	**$ 514,202**	**$ -**	**$ 514,202**
5.0	Optimize Building Energy Management Using Environmental Forecasts	$ 50,000	$ 179,430	**$ 229,430**	**$** Unspent	**30**
6.0	Outreach	$ 17,343		**$ 17,343**	**$ 16,865**	**$ 34,208**
7.0	Technology Transfer Activities	$ 11,081		**$ 11,081**	**$ 11,081**	**$ 22,162**
8.0	Production Readiness Plan	$ 11,081		**$ 11,081**	**$ 11,081**	**$ 22,162**
	Grand Totals	**$ 1,032,806**	**$ 693,632**	**$ 1,726,438**	**$ 1,025,822**	**$ 2,752,260**

Task 5: Smart Building Control

HVAC scope at risk

- Sandia Smart Building Limitations
  - Real-time control difficult/impossible
    - *Our FCS (Facilities Control System)… operates on the secured network (SRN) on its own domain. Interface with Cool Earth Solar and our FCS system needs additional investigation of the requirements and available signals provided.* - Sandia
    - No digital links, 0-10V analog potentially allowed
  - Sub-sub-contractor (Sandia) resources undefined
    - *"We don't know who to talk to."* – Lawrence

Task 5 Scope Change Options

- Option 1: Independent Smart Bldg control study
  - “Dry lab” modeled system
  - Little/no Cool Earth involvement
- Option 2: EV charging station
  - Install necessary electronics to implement at Sandia LVOC
    - No public access, no parking (charging demo one time?)
- **Option 3: Cancel task**

CES recommends option 3

Discussion

Thank you for supporting our product

Scope Change Request Summary

- Task 2: CPV deployments
  - Option 1: Continue under current terms
  - **Option 2: Change scope to 20kW (recommended)**
- Tasks 3 & 4: Sky imaging and solar forecasting
  - Option 1: Continue current plan
  - **Option 2: “Compound Eye” (recommended)**
  - Option 3: “Modified Carlos”
  - Option 4: Cancel both tasks
- Task 5: Smart building control
  - Option 1: Independent Smart Bldg control study
  - Option 2: EV charging station
  - **Option 3: Cancel task (recommended)**

APPENDIX B

Appendix B: Inflatable Concentrator System for Utility-Scale Power

Inflatable Concentrator System for Utility-Scale Power

Paul Dentinger

Cool Earth Solar

Livermore, CA, USA

P. Dentinger, J. Belanger, J. Page, L. Abrahm, D. Finley, S. French, R. Ingwaldsen, R. Lamkin, J. Liptac, S. Maestas, G. Meess, B. Millar, and K. Ottaway

Today’s Talk

- **Intro to Cool Earth Solar**

- Success criteria for a solar collector
  - Price/performance targets
  - Manufacturing scale-up

- Cool Earth Solar’s Solution
  - Inflated Concentrator Module (ICM)
  - Roll-on-ground 2-axis tracking

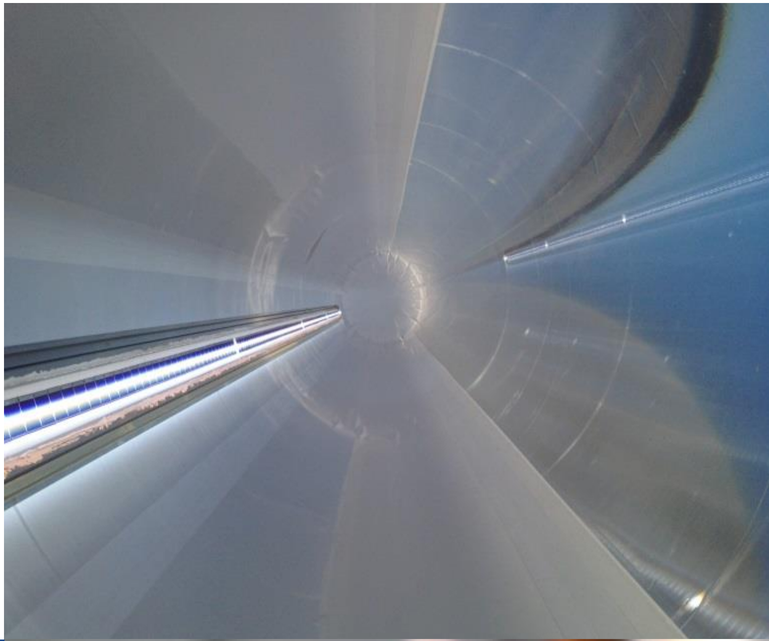
Cool Earth Solar

Focused by an idea

- The solar served market size is massive
  - Over 200 solar companies have failed in the last decade
    - Failed to scale, access to capital "won"
  - 99.9% build-out is *still* in the future
    - "Access to capital" doesn't scale
- Our differentiation: *eliminating barriers to growth*
  - Meet economic & performance targets
    - *Uniquely capable inflated module*
  - Designed for high volume production
    - *Uses existing manufacturing resources & techniques*
  - Capital avoidance through outsourcing
    - *No new factories*

Cool Earth Solar

- Established 2007
- Over $20M investment:
- Unique inflated concentrator optics
  - Utility-scale LCOE
  - High volume design, supply chain
  - Leverages high-efficiency cells
  - Very low capital requirements



Today's Talk

coolearth

- Intro to Cool Earth Solar
- Success criteria for a solar collector
  - Price/performance targets
  - Manufacturing scale-up
    - No ***inventions*** required (Technical risk reduced)
    - No ***resource constraints*** (Supply chain risk reduced)
    - No ***financial burdens*** (Viable business model)
- Cool Earth Solar's Solution
  - Inflated Concentrator Module (ICM)
  - Roll-on-ground 2-axis tracking

Price/Performance

- Cool Earth module ½ of the $/W of flat panel
  - Cool Earth: $0.24 in 2016, $0.22 in 2020
- Market leading LCOE (10MW, Phoenix, 6% equity)
  - Cool Earth **$0.048/kWh in 2020 (ITC), $0.063/kWh in 2020 (no ITC)**
- Superior upfront costs from Cool Earth technology
  - Lowest cost, robust 2-axis tracking
    - Total Cool Earth system **$1.10/W in 2016, $0.99/W in 2020**

Great economics,
but forecasts always look good…
Will it scale?

Manufacturing Requirements of Scaling

- No Technical Risk
  - Hit the price/performance forecasts
  - Allows bankability
  - *Example: film lifetime*
- No Supply Chain Risk
  - No materials constraints
  - Local production, multiple suppliers
  - *Example: automotive robotic lines for frame*
- No Financial Barriers to Scaling
  - Investment capital avoidance
    - Capacity expansion is costly (continuing need for money)
    - Fixed costs in an uncertain marketplace (expensive money)
    - Time scale management (impatient money)

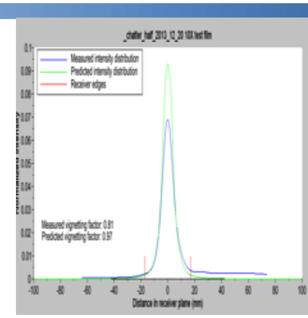
Today's Talk

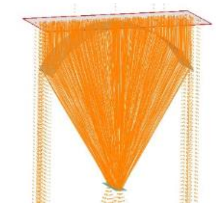
coolearth

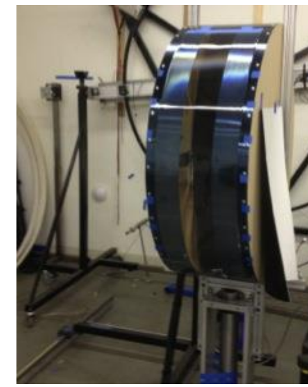
- Intro to Cool Earth Solar
- Success criteria for a solar collector
  - Price/performance targets
  - Manufacturing scale-up
    - No ***inventions*** required (Technical risk reduced)
    - No ***resource constraints*** (Supply chain risk reduced)
    - No ***financial burdens*** (Viable business model)
- Cool Earth Solar's Solution
  - Inflated Concentrator Module (ICM)
  - Roll-on-ground 2-axis tracking
  - Energy and Performance

Cool Earth Status Update

Inflated Concentrator Module

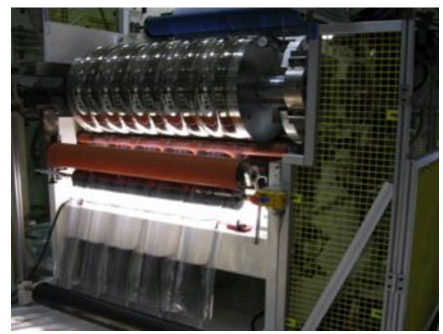






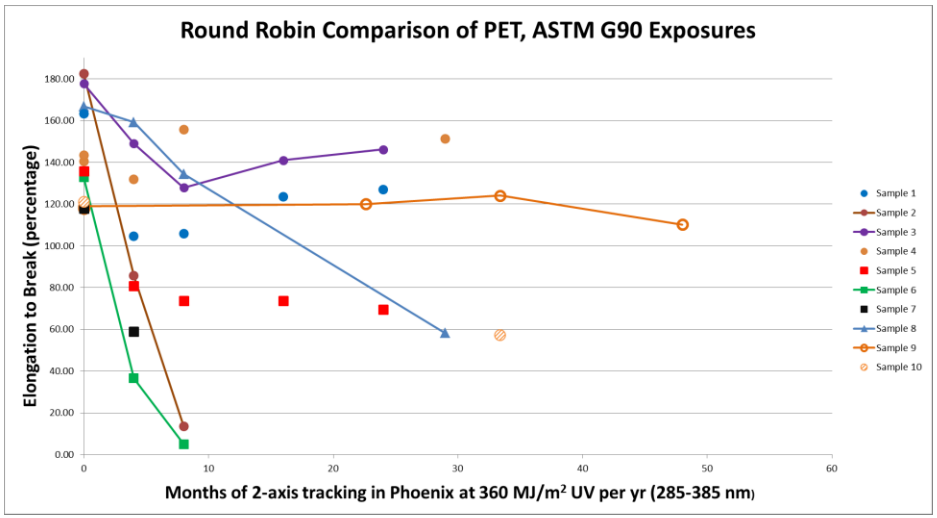
- Performance
  - Optical design tools and testing capability correctly predict actual 20 sun results

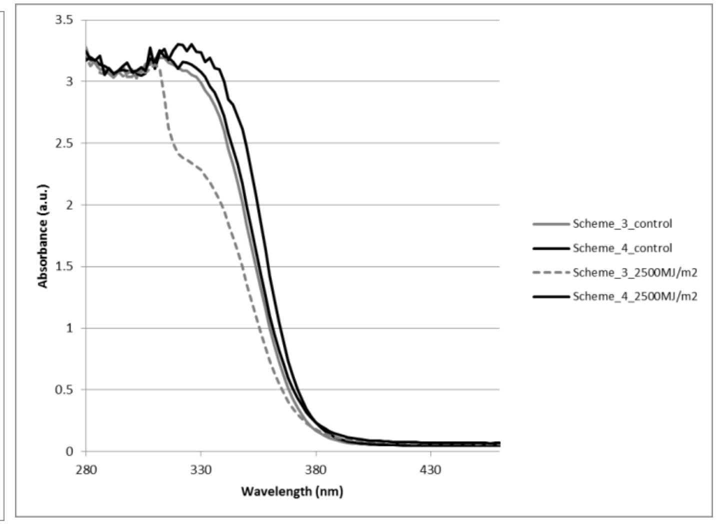
    "The light we expect to be hitting the cells, is hitting the cells."



- Manufacturability
  - Full size optic assembly
    - Multiple tubes built, stable process
  - Large potential ROA benefit
    - Existing lines capable of 250MW/yr w/o capital
    - Less than $10M capital to scale to 1GW

Cool Earth Status Update
Thin Films





Poor PET suffers from UV damage, but properly engineered PET does not.

For properly engineered materials, no UV-induced optical change up to 7+ years in Phoenix.

Films are several thousandths of an inch thick, and withstand weather enough for moderate replacement schedules, deferring costs until further in the project. See poster P. Dentinger, et al.

Highly Reliable 2-axis Tracking at 1-axis cost

Open frame construction

- Easily adapted to high volume mfg
- High strength/weight ratio

Low cost actuation

- Support separate from movement
- Leverage advantage

Highly Reliable 2-axis Tracking at 1-axis cost

<u>Single-board local SCADA</u>

- Closed loop tracking
- High volume, low cost
- Req: 0.5 deg. Ele, +/– 1 deg. Azi.

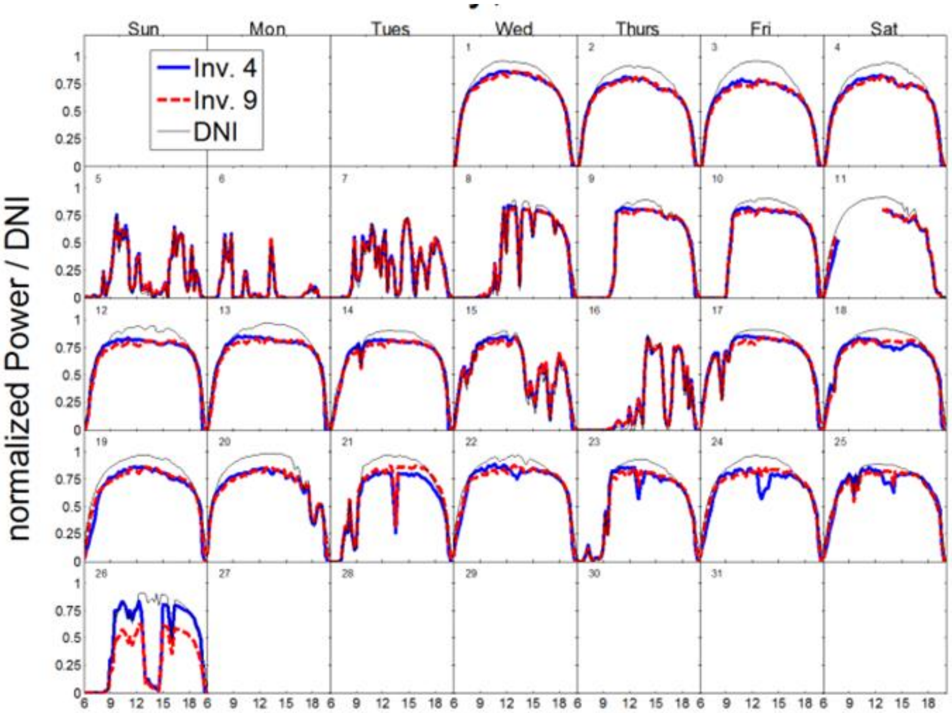
<u>Roll on ground design</u>

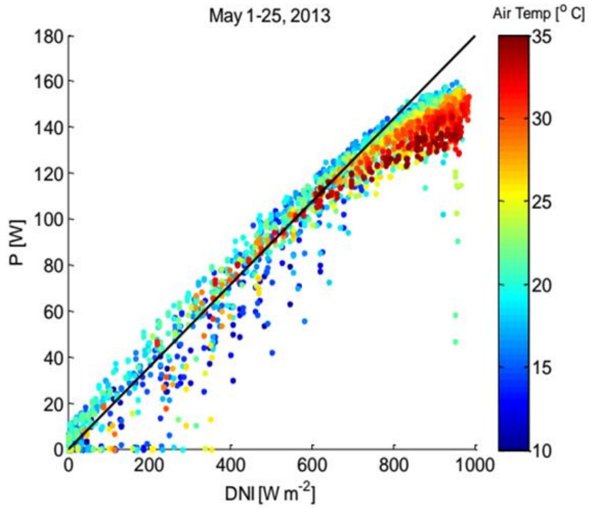
- Ground screw at axis
- Rapid, low cost install

<u>Aided by low loads</u>

- Tubes ~7 lbs. (6 film, 1 air)
- Drag coefficient for cylinder ~1/3 of flat panel

Energy: Commercial Optic and Cells, May 2013





Data courtesy of M. Lave, Sandia National Labs

- Shape stability of inflated concentrator good.
- Tracker/BOS on target.

Cool Earth Solar Solution

- Novel solar collector system design
  - Price/performance advantages
  - Manufacturing scale-up
    - No ***inventions*** required ✔
    - No ***supply constraints*** ✔
    - No ***financial burdens*** ✔

APPENDIX C

Appendix C: Thin Polymetric for Inflatable Concentrator Optics

Thin Polymeric Films for Inflatable Concentrator Optics

Paul Dentinger

Cool Earth Solar

Livermore, CA, USA

With Contributions from

Marina Temchenko and Samuel Lin

Goal

Get the greater CPV community cognizant and knowledgeable about the CES system.

Indicate that inexpensive, thin films can be used for front-facing, concentrating solar applications.

The use of PET-based films for concentrating solar is covered by

1. US Patent 8,074,638 also issued in China, and published in Europe, India, Taiwan
2. PCT/US2011/050703 Sep 7, 2011
3. PCT/US2011/067672 Dec 28, 2011
4. 13/676,437 Nov 14, 2012
5. PCT/US2012/065279
6. US/2012/61/652,114
7. PCT/US2011/050703 Sep 7, 2011

Background

Opportunity

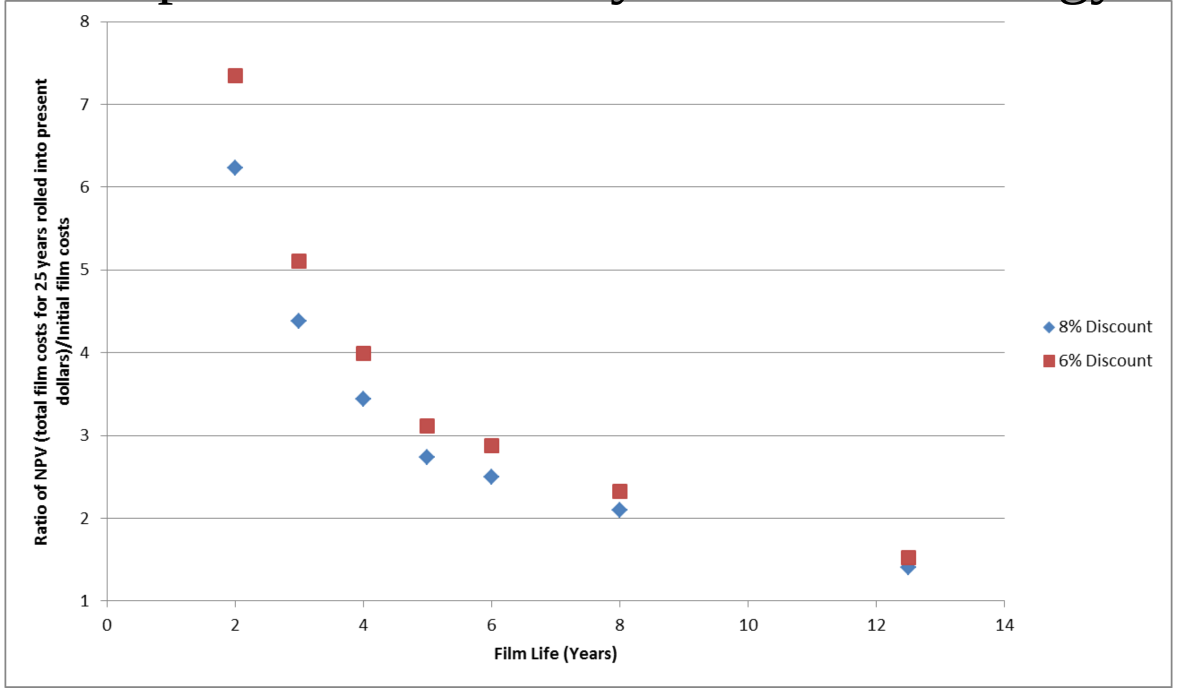
- Commodity grade PET can be procured for \$0.03 to \$0.04/ft2. for 0.002 in. thick film, and is in use for outdoor, high volume applications for water, agricultural products packaging, etc.
- Thin film optics offer trivial scale-up, and require near zero capital costs.
- The energy to break for PET is ~20x better than acrylics, and dimensional stability is vastly greater, minimizing material use.
- Silicone on glass and large glass mirrors also suffer from high upfront costs.
- Large upfront costs force long life components which in turn fuels long qualification times, custom processing, custom factories, etc.

Solution

- Allow for replaceability. Design for scale and actively trade-off upfront cost with replaceability to minimize LCOE and return on assets (ROA).

Net Present Value Analysis of Replaceable Subsystem: Optics.

Net Present Value analysis for any a technology deemed for replacement vs. 25-year life technology.



A technology with ½ the upfront cost requires only ~1/3 the lifetime, even including O&M.

There is also a warranty, reliability, and degradation advantage of needing to prove only 8 year life.

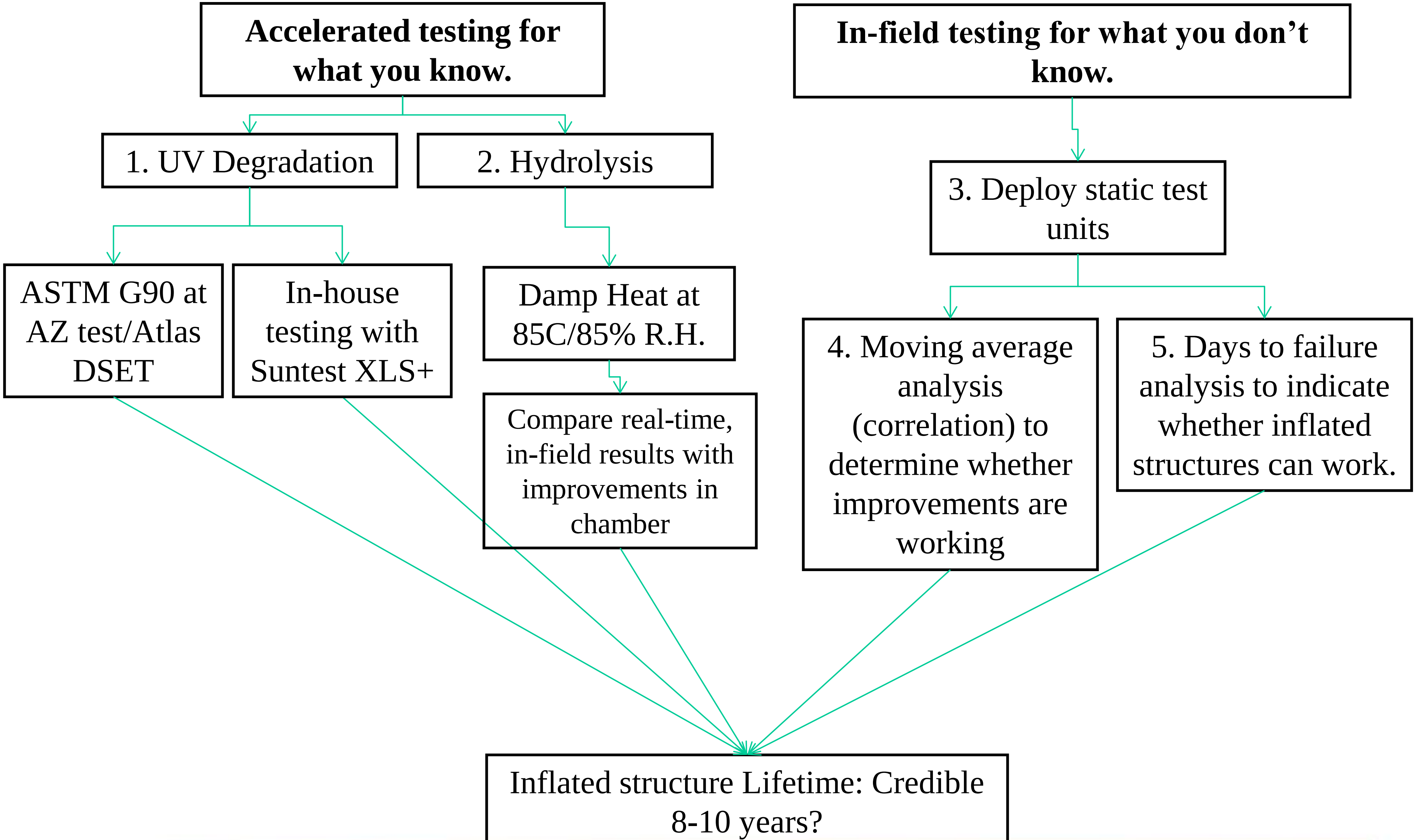
MCPV Optic Costs Analysis

If a mirror costs $35/m^2 to build and support, I would argue that an 8-10 year lifetime film was superior if it can be done for less than $17.5/m^2.

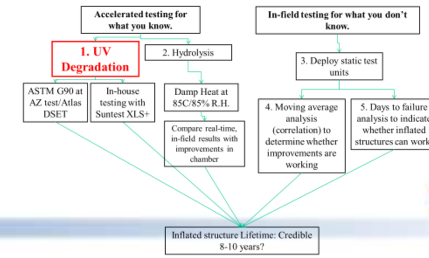
PET films are far less than ½ the price of a glass mirror, and they require no capital costs for scale.

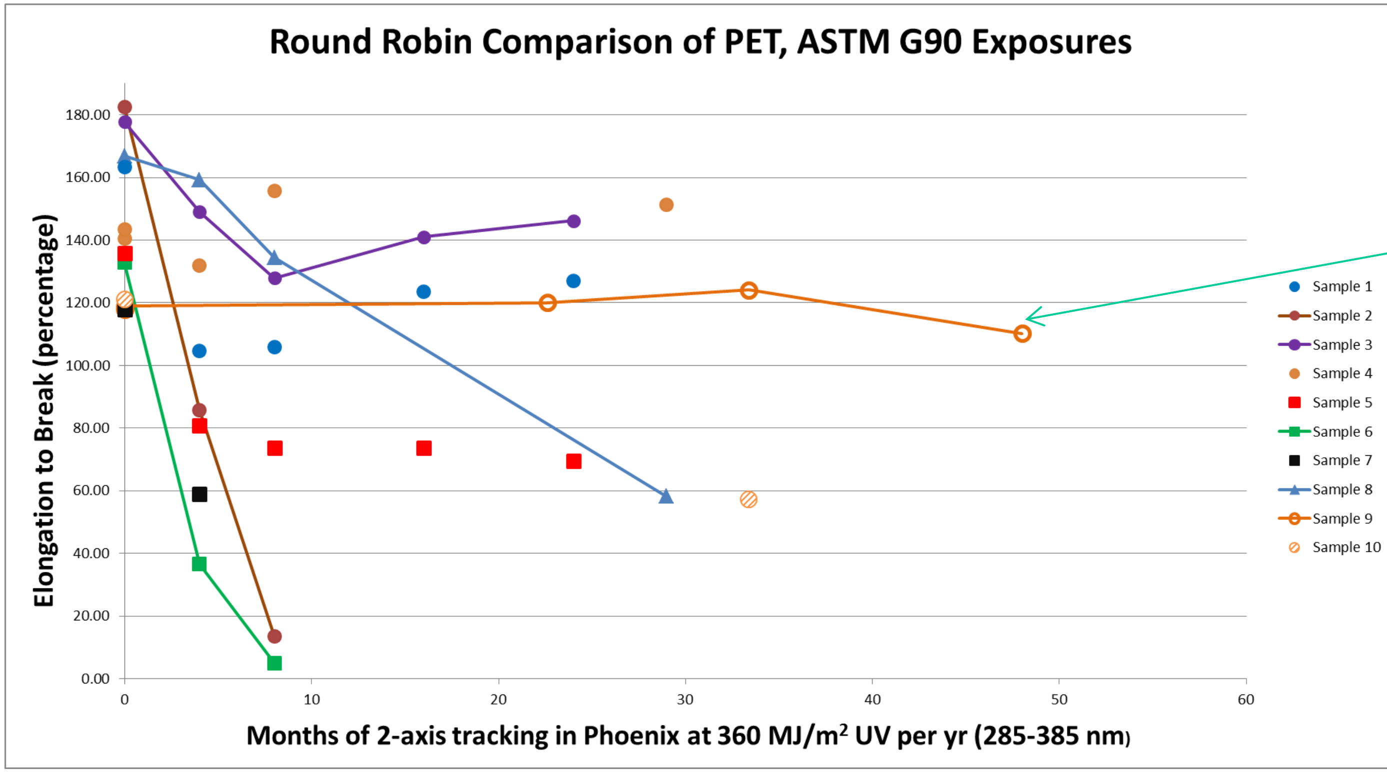
Can a PET film survive 8-10 years of 2-axis tracking unattended in the elements?

PET Film Lifetime Testing Strategy



1. UV Degradation; Round Robin of PET Film Sources



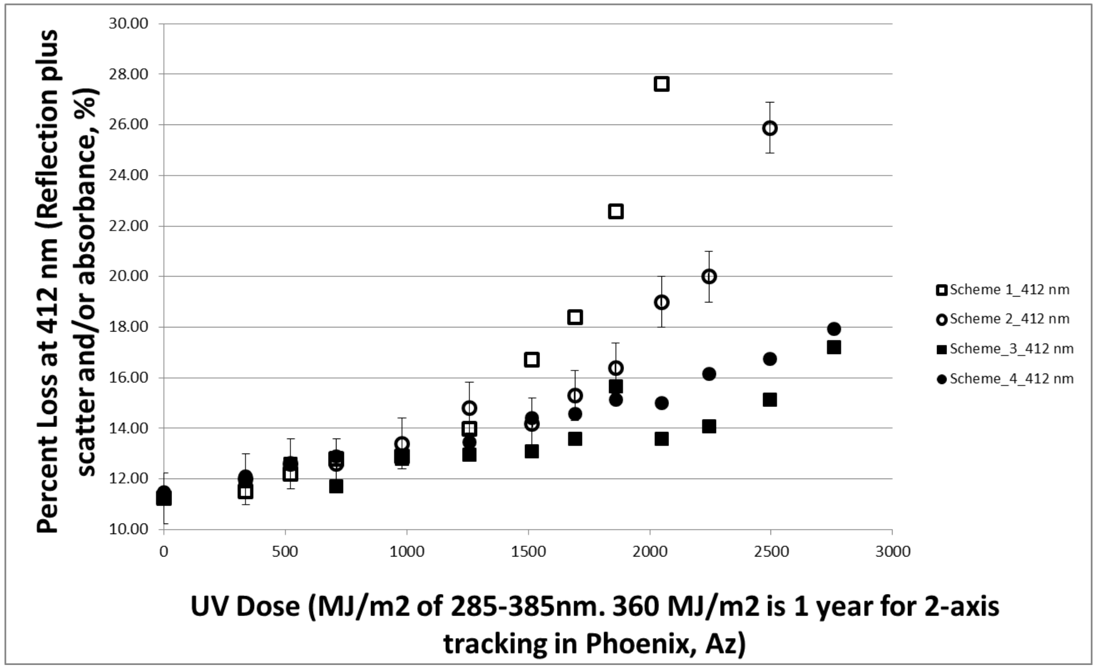


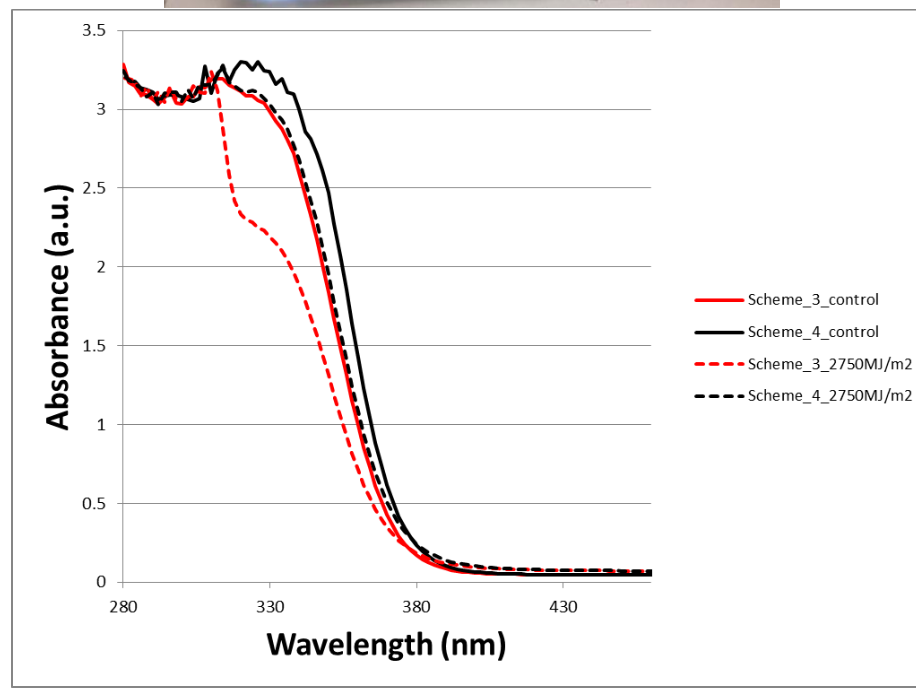
VueTek film from Madico, Inc. shows no degradation at 4 years exposure in Phoenix, ASTM G90

Raw PET shows detectable degradation at approximately 1.5 months, while most PET films show degradation between 3-12 months.

Poor PET choices corroborate literature suggestions of UV degradation followed by mechanical properties degradation. VueTek films from Madico, Inc. are not susceptible to this mechanism.

1. UV Degradation- Beyond 4 years exposure doses- Weatherometer

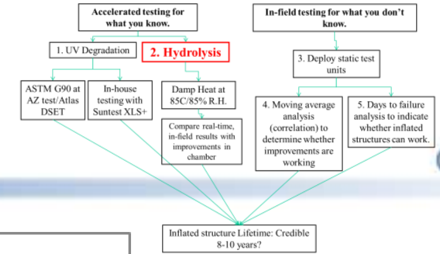


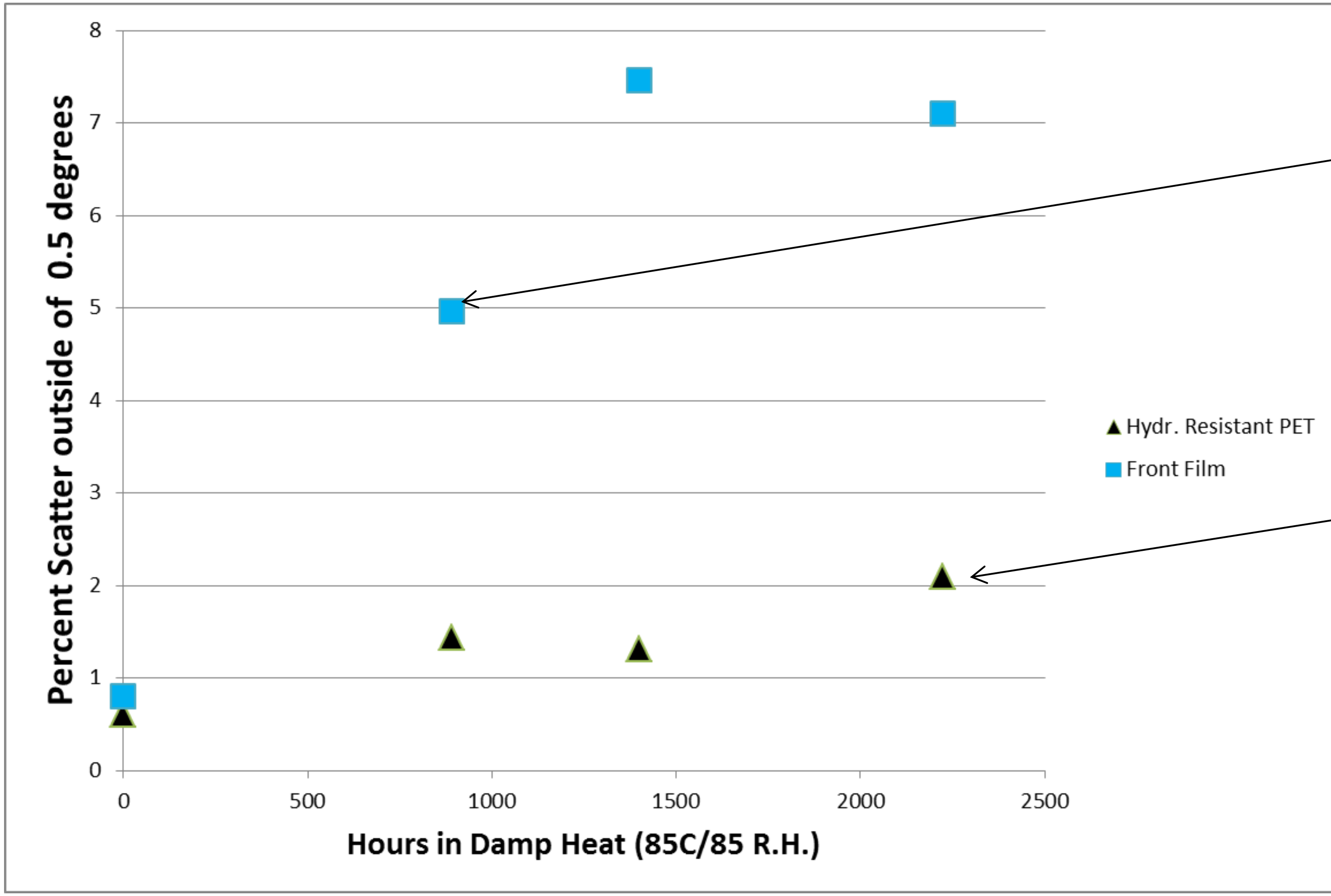


- Photobleaching followed by "yellowing" and rapid loss of mechanical properties (data not shown) for schemes 1 and 2.
- No yellowing and no mechanical loss for schemes 3 and 4.

- Scheme 3 shows evidence of photobleaching but not yellowing as yet.
- Scheme 4 shows no evidence of UV damage up to 7+ years of dose in Phoenix.

2. Hydrolysis of PET - Haze





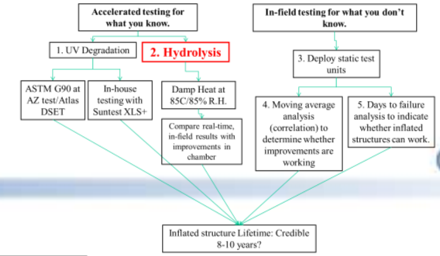
This material shows 0.5% increase in haze in > 3 years in-field results.

Hydrolysis resistant material develops haze ~5x slower.

Modern HR PET materials easily achieve 10-15 years lifetime based on haze increase.

MADICO ISO 9001 & 14001 Certified

2. Hydrolysis- Mechanical Properties



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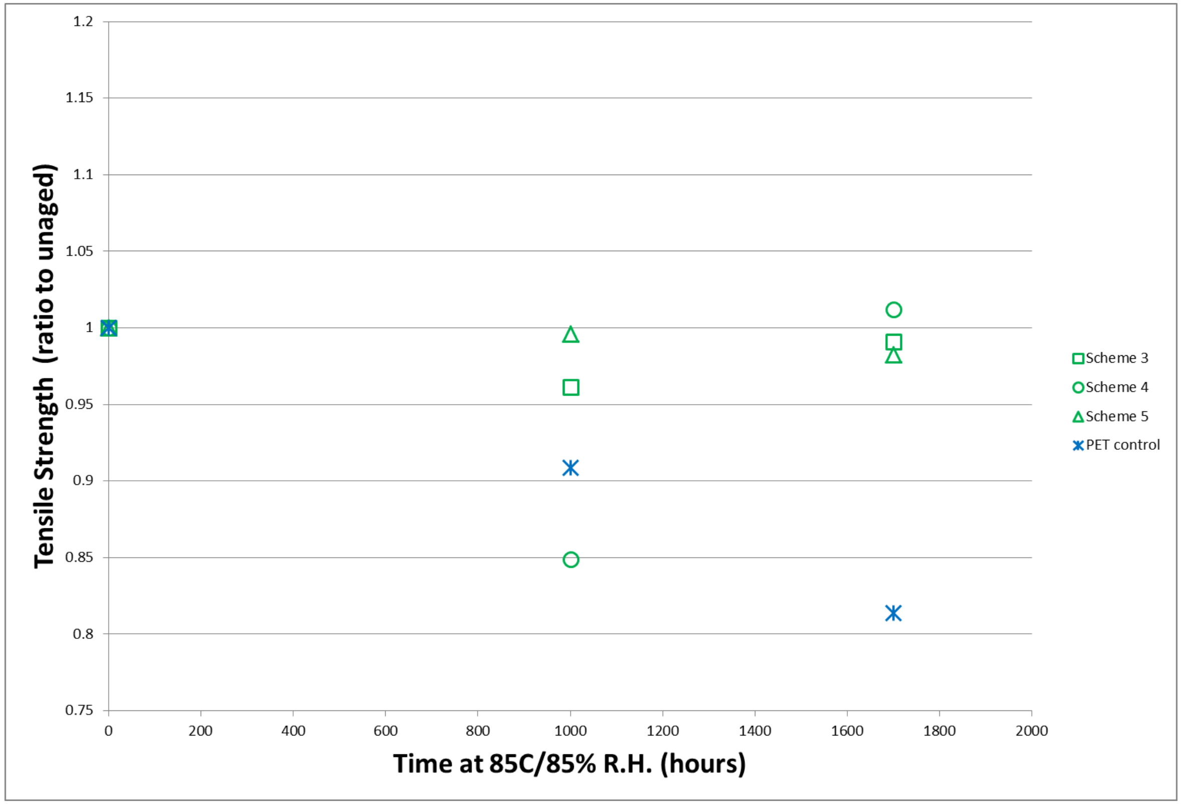
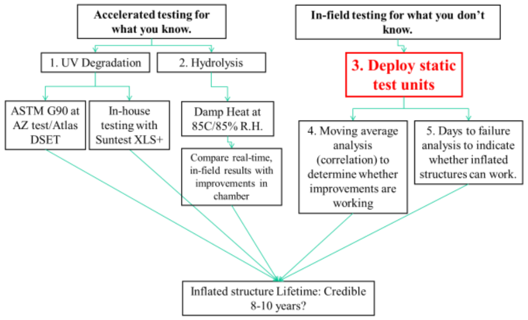


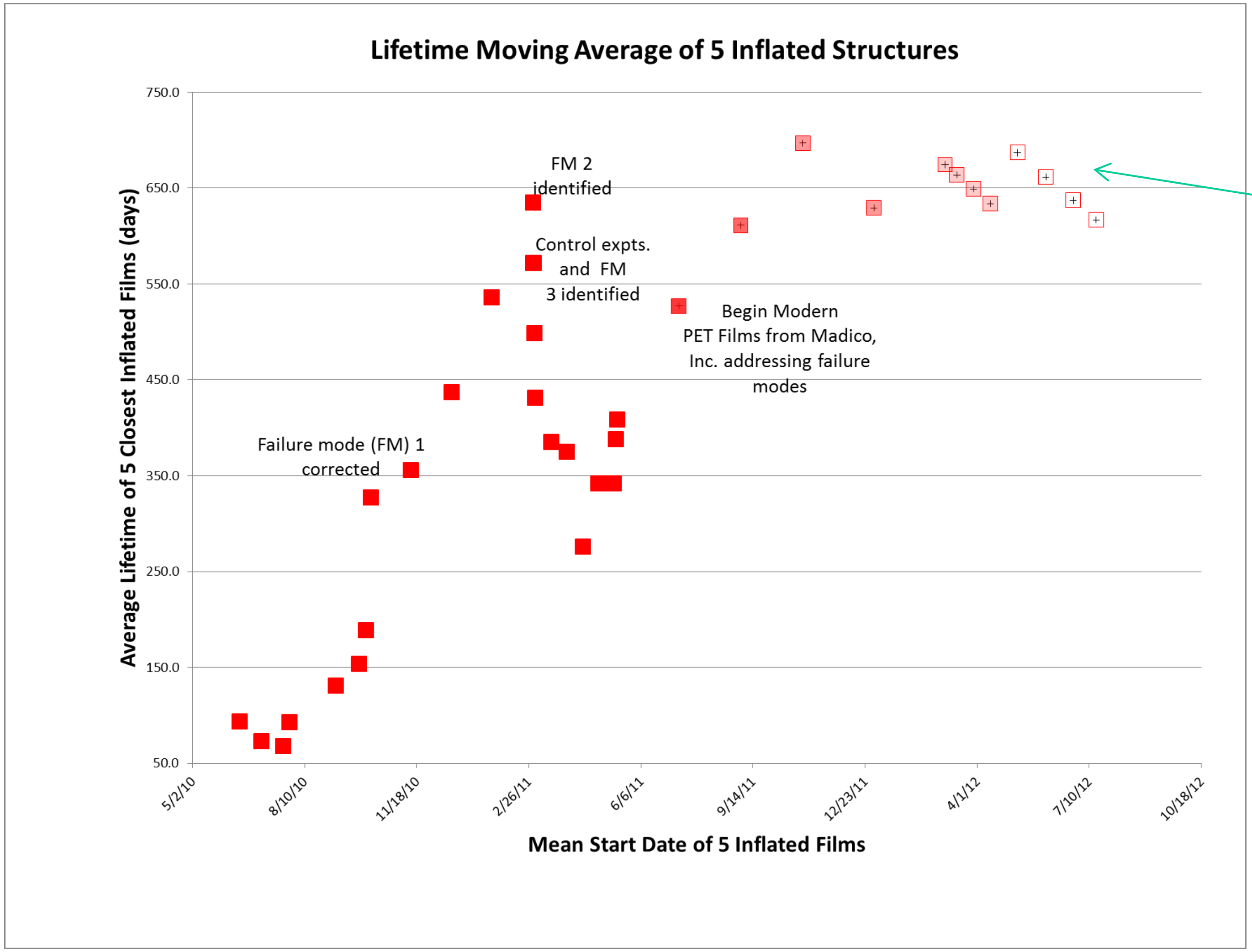
Mechanical degradation of PET due to hydrolysis is manageable with modern PET up to > 10 years equivalent exposure.

3. Deploy Static Test Units



Static Test Units are inflatable structures deployed outdoors and time to failure is the primary metric.

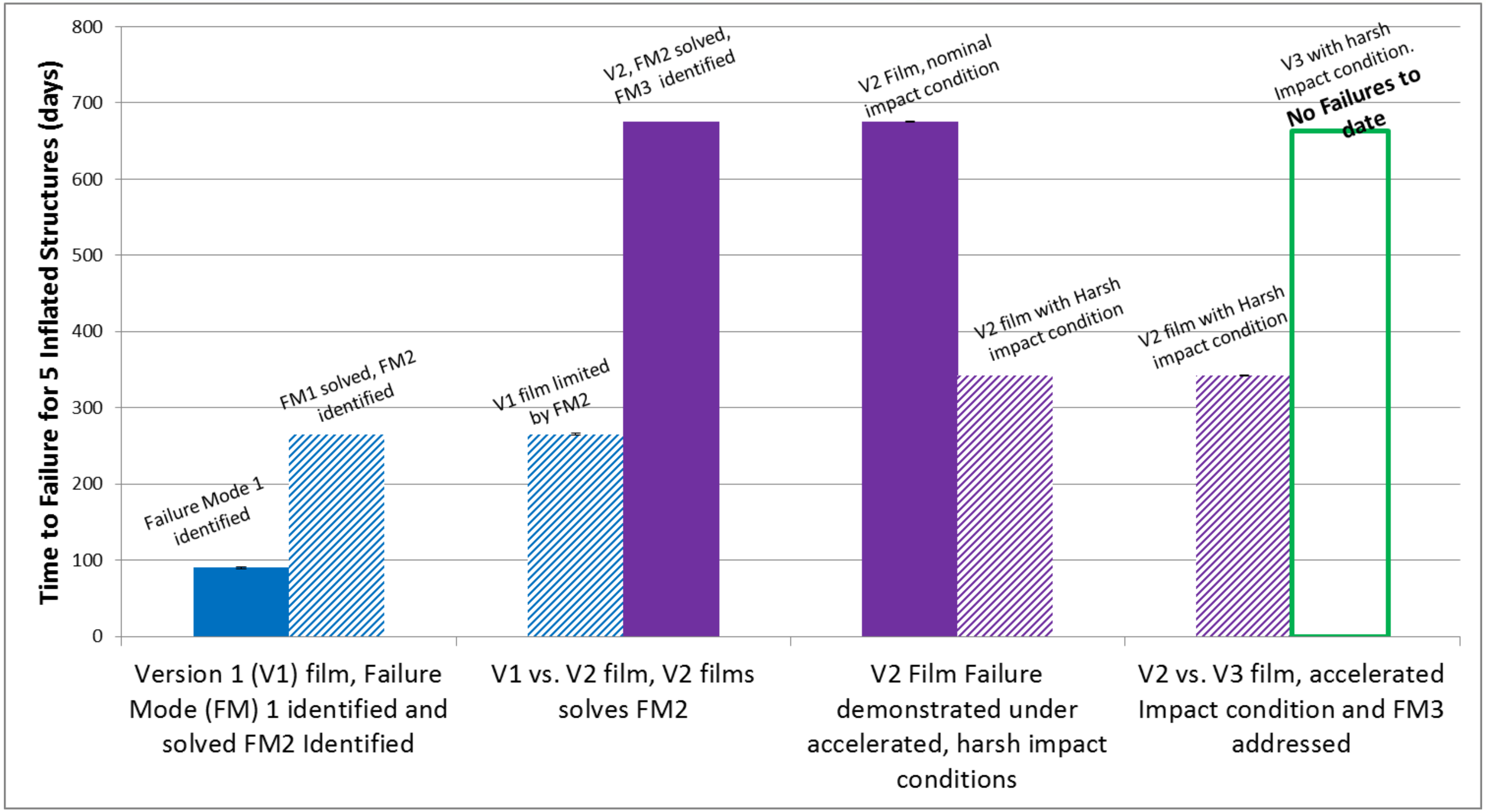
3.1 Moving Average Analysis of Static Test Units



Transparent markers indicate inflated structures still in tact and under test.

VueTek film from Madico, Inc. does not fail at 650+ days, while standard or even advanced PET does.

3.2 Static Test Results-Direct Testing of Variables



Version 3 (V3) film is VueTek from Madico, Inc. and shows outstanding UV and hydrolysis resistance.

Very strong correlation between improvements in accelerated testing, and improvements in inflated structure life in the field

Summary

- Net Present Value Analysis is used to trade-off up-front optics costs vs. lifetime of systems, minimizing LCOE for the system.
  - With 8-10 years of film life, the initial cost needs to be less ~1/2 the cost of competing technologies, and then it is considerably beneficial to use low cost optics.
  - PET-based optics are far less expensive than glass mirrors, glass silicone, or acrylic based optics.

- The two most reported failure modes for PET in weather environments are UV and hydrolysis.
  - Accelerated UV aging clearly shows paths to greater than 10 years with low cost, PET based optics from Madico, Inc.
  - Accelerated aging via damp heat clearly indicates a path to greater than 10 years.

- Static Test samples at 1x aging show that the failures with initial films are overcome with modern films.

- There is a strong correlation between performance in accelerated testing and performance in the field, and accelerated testing shows clear paths to 8-10 year film life.

Conclusions

- The Cool Earth Solar System uses inflated, thin film PET structures to provide exceedingly low cost optics for mid and high concentration solar applications.

- It is shown that low cost PET optics provide much better overall life cycle costs while simultaneously circumventing the need for proving 25 year life, and having near complete capital avoidance for optic manufacturing.